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ORIGINAL ARTICLES.

Chalky Boulder-Clay at Wembley Park.

By H. G. Mantle, M.I.Mech.E., F.G.S.

(PLATE XX.)

THE Exhibition Grounds, which include the site for the Empire Stadium as well as for the British Empire Exhibition, comprise an area of roughly 216 acres. The north-eastern boundary runs parallel with the Metropolitan Railway, and the North Entrance to the Exhibition is only a few yards south of Wembley Park Railway Station bridge. At or near the station the mean level is about 110 feet above O.D.; but the surface of the ground is uneven, and rises to 210 feet above O.D. at Wembley Hill, outside the south-western extremity of the Exhibition area. The Wealdstone Brook runs irregularly along the northern boundary in an easterly direction in the neighbourhood of the Amusement Park, but for the sake of convenience its regular course has been slightly diverted at this point and an old lake filled up. The main sections to be described are north of the brook.

The area is shown on the Geological Survey maps as London Clay; but this term applies only to the solid formation beneath superficial deposits of varying thickness, now known to be present at several points.

In 1922 the extensive excavations involved in the erection of the Exhibition buildings and offices exposed sections of considerable geological interest. At Wembley Park Station some excavations were made for the widening of the line and the provision of additional platform accommodation and other facilities. These excavations commenced near the bridge, where, on the north side of the line, the foundations for a wing-wall extend about 22 ft. below the road-level. The surface of the ground here also is irregular, and falls on the line of excavation in a south-eastward direction. At the wing-wall end of the section the London Clay was reached at about 12 ft. below the surface, and for about 9 ft. above the top of the clay the material is a brownish rubbly drift clay, with stones, chiefly flints, occurring irregularly in the mass; the remaining 3 ft. to the surface is made ground capped by the ordinary road-metal. But a dozen yards from this point in a south-east direction, the cutting displayed a section 25 yards long showing here and there, beneath 5 or 6 ft. of rubbly drift clay, a stony bluish clay (Chalky Boulder Clay) thickly crammed with rounded and subangular water-worn flints of various colours, associated with other pebbles and fragments such as chert, jasper, quartz, sandstone, granite, quartzite, trap, limestone, and small pieces of pure chalk. Generally it is a lenticular mass running occasionally into pockets, where the deposit becomes as hard and compact as Scotch till. It contains also thin intercalated beds of sand or sandy gravel. I could not ascertain its total thickness, but it was exposed 18 in. to 2 ft., and was not bottomed where it was seen to pass beneath the end of the old platform.

Subsequently, however, in February, 1924, I traced its extension laterally into the Exhibition Grounds on the south side of the railway, where at the Colonnade section I found it in contact with the London Clay. This section showed about 6 to 7 in. of surface soil (covered with growing timber), followed downwards by 5 ft. 6 in. to 6 ft. of rubbly drift clay with a variety of stones and at the base a band of about a foot in thickness of Chalky Boulder Clay resting on a wavy surface of the London Clay and dipping into a pocket at the right-hand bottom corner. The dark-blue clay beneath this well-defined line of contact represents the upper part ot the London Clay formation, with its intercalated bands of septaria in nodular and tabular forms. This cutting is about 24 ft. across, and the compact stony boulder-clay extends along the whole length of the exposure.

Farther south, at an excavation for an ornamental lake running due east and west, a similar sequence occurs, with the addition of a fine exposure of a band of septaria 6 in. thick running parallel to the line of the lake.

In the Amusement Park area, farther east from the Colonnade section and near the boundary fence, excavations were made for the erection of a large motor garage, and here below 4 to 6 ft. of rubbly drift clay covered with old growing timber was exposed a remarkable bed of extremely tough brownish to grey chalky boulder-clay containing, in addition to the kind of stones already mentioned, several spherical flints, known as cannon shot, one measuring 3½ in. in diameter and 10½ in. in circumference, and weighing two pounds, with its surface completely pin-pitted, with here and there larger holes up to a quarter of an inch in diameter, with external colour chalky; also a much larger admixture of pure chalk, from small pieces up to large irregularly shaped lumps 3 or 4 in. in diameter, some more or less silicified, and varying in colour (on fracture) from pure white to shades of dingy yellow or brown, owing to the presence of peroxide of iron.

The thickness of this bed could not be ascertained; but it was proved in places to be 3 ft. 6 in. to 5 ft. 6 in. thick and to extend towards the newly diverted line of the brook. I fortunately obtained an excellent photograph of this section, taken at my request by the Topical Press Agency, which well displays the overlying rubbly drift material, at the base of which occur large angular blocks of light buff-coloured hard sandy limestone varying in size up to 22 in. long by 18 in. wide by 9 in. thick. This limestone is richly fossiliferous. Some of the bivalves resemble forms that I have taken out of the lower fossiliferous horizon of the London Clay at the new Littleton Reservoir, *Cyprina scutellaria* being a characteristic one, but the matrix in which they are embedded is, as stated, harder and of different colour. If derived from the London Clay it is not unlikely that these blocks may originally have formed part of a large boulder that had been transported from a distance and had got broken and mixed up with the general drift accumulations. I found on some tipped material adjacent a few pieces of hard pink chalk and fossils probably from the East Coast, whilst workmen showed me some small teeth of sharks that they said they picked up in the excavations.

On the south side of the Stadium a road-cutting was made through stiff drift clay, including, in addition to the usual stones, large nodular and tabular flints as well as many septaria. This occurrence in its deepest part is about 6 to 7 ft. thick down to the road-level. On the western side as well as in other places has been encountered near the surface a bed of bright-yellow plastic clay with comparatively few stones, and those principally rounded flints.

Amongst the surface-stones and boulders I have examined, in addition to those already named I have found several small sarsens more or less worn on the edges, but have not seen or heard of any large blocks being found in the area, similar to those occurring chiefly on or near the surface at Sudbury, a little to the west, and at Kingsbury and Hendon to the north-east, of Wembley Park.

It may be interesting to recall at this point the fact that whilst workmen were excavating for the then new Metropolitan Railway Station at Wembley Park in 1890, they discovered in a gravel band below 10 ft. of drift clay the remains of a hippopotamus.[1] This band of gravel, which was about a foot in thickness, had a clayey matrix and contained flint pebbles and fragments of septaria. During the same year fragments of bone belonging to similar animals were also found in the lowest gravel at Finchley.

I have submitted several small boulders found in the drift deposits to Dr. H. H. Thomas for examination and he has pronounced three to be definitely ice-worn and striated, one of flint being considered particularly interesting. The other two erratics are hard silicified chalk nodules. Mr. John Pringle has kindly identified the following fossils, also found in the same deposits, viz. No. 1 may be possibly the cast of the exterior of an Echinoderm ; No. 2 are two fragments of shell that may be referred to *Pecten* (*Aequipecten*) *beaveri* J. Sowerby, a characteristic Lower Chalk fossil; No. 3, specimen of flint with an impression of *Spondylus*, Chalk formation; No. 4, two specimens of *Cyprina scutellaria* Lam., London Clay formation.

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[1] *Quart. Journ. Geol. Soc.*, vol. xlviii, 1892, p. 468.

These discoveries, taken in conjunction with what we have described of the nature and character of the superficial deposits, prove that the ground of the Exhibition area, between the surface soil of 6 or 7 in. and the underlying London Clay, is composed of Glacial drift clay and boulder-clay of varying thickness, and that the former may perhaps be regarded as the weathered and disintegrated representative of the latter and may well constitute an extension of the Great Chalky Boulder Clay series of Finchley and of Hendon, which latter place lies within about three miles, as the crow flies, north-east of Wembley Park. But the foundations of the great buildings of the Exhibition have penetrated these overlying superficial deposits and rest for the most part on the London Clay itself.

On the Unconformity at the Base of the Ashgillian in the Bala District.

By B. B. BANCROFT.

THE possibility of an unconformity at the base of the Ashgillian in North Wales seems to have suggested itself to several of those who have worked in that region. A definite verdict, however, has never been recorded, and the prevailing, if not general, view is that the Caradocian and Ashgillian are everywhere conformable.

Nevertheless, some of those who have investigated the sequence have encountered difficulties, and, as faulting proved inadequate to explain the local variations, the possibility of an unconformity could not be entirely eliminated. Dr. Elles appears to have regarded the junction between these two formations as conformable (1)[1], and her view has been accepted by Mr. King (2) whose statement that "recent work by Miss Elles rules out any possibility of an unconformity between the *Orthis actoniae* Beds and the basal Ashgillian" doubtless reflects the general opinion. But an examination of the data set forth by Dr. Elles discloses no criteria which might justify so definite a pronouncement, and when the problem is reviewed with the assistance of adequate faunal data the inevitability of an unconformity is immediately established.

The present communication is the result of careful collecting in the Allt ddu and Gelli grin Series during June of last year, and this work appears to me to demonstrate a pre-Ashgillian disturbance in the Bala country.

The evidences of unconformity are derived in the first place from the character and faunal succession of the Gelli grin Series, with

[1] Figures in parentheses refer to Bibliography at end of article.

THE PRINCIPAL SECTIONS.

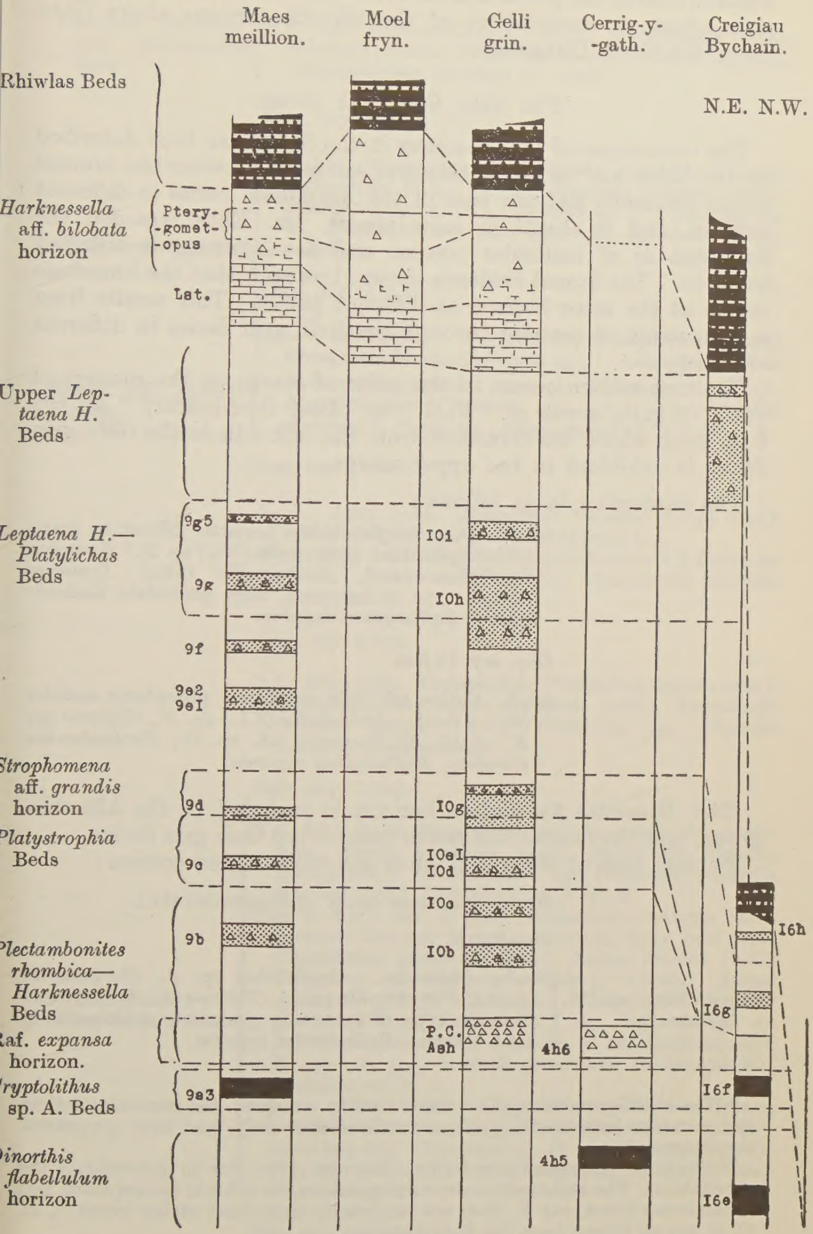

FIG. 1.

which is related the position of the Bala limestone, and, in the second place, from an examination of the hill-side sections above Glyn bach, E.S.E. of Llangower.

The Gelli Grin Ash Series.

The occurrence of the limestone in the Series has been described by Dr. Elles, and as the thickness of sediment between the summit of the limestone and the base of the Ashgillian varies in different sections, and is absent in some places, Dr. Elles regarded the limestone as of lenticular nature and as occurring at different horizons. The faunal evidence shows, however, that the limestone occurs at the same horizon at different places. This results from a comparison of sections through the Gelli grin Series in different localities.

The first section occurs in the series of scarps on the summit of Cerrig y gath, south of "Foel" in "Foel Caer-hafotty" on the 6 in. map, where the transition from the Allt ddu to the Gelli grin Series is exhibited in the upper scarps.

The succession is as follows:

4 h 5.[1] *Dinorthis flabellulum* horizon. Mudstone scarp with *Cryptolithus*, *Dalmanella* (S.L.) sp. *E.*,[2] *Dinorthis flabellulum* (v.c.), *Harknessella* (abt.), *Leptaena* (simple type of interiors), large geniculate Rafinesquinid, *Rafinesquina expansa.*

Gap, say, 12 feet.

4 h 6. Coarse ash with occasional phosphatic nodules (say, 4 feet). *Dalmanella* (S.L.) sp. *E.*, *Cliftonia* sp. *K.* or aff. *K.*, *Leptaena* aff. sp. *G.*, *Plectambonites rhombica*, *Rafinesquina expansa.*

The *Dinorthis flabellulum* horizon is included in the Allt ddu group, and the Coarse Ash is the base of the Gelli grin Series.

Further east at Maes meillion is the following succession:

9 a 2. Mudstone scarp. *Harknessella* (abt.).

Small gap.

Cryptolithus sp. *A.* horizon.	9 a 3. Mudstone. *Cryptolithus* sp. *A.*, *Harknessella* (abt.), *Platystrophia* (rare), *Cliftonia* sp. *K.*, *Leptaena* (simple type of interiors), geniculate Rafinesquinid (4 h 5 form), *Rafinesquina expansa.*

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[1] The initial number is the writer's locality number; the remaining letters and numbers indicate the position in the section only, and have no general significance.

[2] The letters represent new forms; they are given here to demonstrate the correlations. The alphabetic order corresponds to the order in the sequence, but a particular letter, say E, does not necessarily mean that earlier forms A, B, C, D, are all known from the Bala district.

	Gap, say, 15 feet.
Plectamb. rhombica and *Harknessella* Beds.	9 b. Ash. *Dalmanella* (S.L.) sp. *E.*, *Harknessella* (abt.), *Nicolella actoniae*, *Plectorthis* sp. *A.* (v. abt.), *Cliftonia*, *Plectambonites rhombica* (v. abt.).
	Gap, say, 6 feet.
Platystrophia Beds	9 c. Ash. *Cryptolithus* aff. *gibbifrons*, *Platylichas laxatus*, *Dalmanella* (S.L.) sp. *E.*, *Nicolella actoniae* (abt.), *Plectorthis* sp. *A.* (c.), *Cliftonia* sp. *D.*, *Leptaena* sp. *G.*, *Plectambonites* (sm. sp.), *P. rhombica*, *Platystrophia*.
	Gap, say, 5 feet.
Stroph. aff. *grandis* Beds.	9 d. Mudstone. *Cryptolithus*, *Platylichas laxatus*, *Brongniartella* sp., *Calymene* sp., "*Acaste*" *apiculata*, *Dalmanella* (*canalis* group), "*Dalmanella*" sp., *Platystrophia*, *Cliftonia* sp. *A.*, *Plectambonites rhombica* ?, *P.* sm. sp., *Strophomena* aff. *grandis* (c.).
	Gap, say, 13 feet.
	9 e 1. Ashy beds. *Dalmanella* (*canalis* group) (abt.), "*Dalmanella*" sp., *Nicolella actoniae* (c.).
	9 e 2. Ashy beds. *Cryptolithus gibbifrons* (abt.), *Calymene* (abt.), *Brongniartella* (abt.), *Dalmanella* (*canalis* group) (abt.).
	Gap, say, 4 feet.
	9 f. Ashy beds. *Cryptolithus*, *Platylichas laxatus* (abt.), *Brongniartella*, *Acaste apiculata* (abt.), *Dalmanella* (*canalis* group) (v.c.), *Plectorthis* sp., *Nicolella actoniae*, *Cliftonia* spp.
	Gap, say, 7 feet.
Leptaena H.—*Platylichas* Beds.	9 g. Ashy beds. *Cryptolithus gibbifrons* (c.), *Brongniartella*, *Acaste apiculata* (v.c.), *Dalmanella* (*canalis* group) (abt.), "*Dalmanella*" sp., *Plectorthis*, *Nicolella actoniae* (abt.), *Leptaena* (large) sp. *H.*
	Gap to 9 g 5, say, 8 feet. Apparently between these horizons but out of line of section, ashy beds with *Cryptolithus gibbifrons* (abt.), *Lichas laxatus* (v.c.), *Calymene*, *Brongniartella* (abt.), *Cybele*, *Acaste apiculata* (abt.), *Chasmops*, *Dalmanella* (*canalis* group) (abt.), "*Dalmanella*" sp. *Cliftonia* sp. *A.* (c.), *Plectambonites* aff. *5-costata*, *P.* sp., Rafinesquinid K. sp. *A.* (c.), several geniculate Rafinesquinids, *Leptaena* sp. *H.* ?
	9 g 5. Ashy beds. *Cryptolithus gibbifrons* (abt.), *Platylichas laxatus* (abt.), *Calymene* (v.c.), "*Acaste*" *apiculata* (c.), *Chasmops* sp. (v.c.), *Plectorthis* (v.c.), *Nicolella actoniae*, *Plectambonites* aff. *5-costata* (abt.), *Leptaena* sp. *H.*
	Gap, say, 25 feet.

9 h 1. Crystalline limestone (say, 6 to 8 feet). *Nicolella actoniae* very abundant.

Harknessella aff. bilobata Beds.

9 h 2. Highly calcareous, and ashy, highly cleaved beds. *Nicolella actoniae* (v. abt.), *Harknessella* aff. *bilobata* (v. abt.). Few feet.

Pterygometopus horizon.

9 h 3. Coarse ashy beds. Large *Plectorthis* (a mould of this shell is seen in the rock face: the fauna cannot be said to have been examined).

These beds are followed almost immediately by the Rhiwlas.

In this section the beds at the base, 9*a*–9*b*, are roughly equivalent to those in the previous section. Near the top of the section the limestone with *Nicolella actoniae* occurs within a few feet of the Rhiwlas.

The section at Bryn Pig has been described by Dr. Elles. There only a few feet of strata separate the limestone from the base of the Rhiwlas Beds.

In the old quarries on Moel Fryn, about 7 feet above a hard crystalline limestone, the following fauna occurs :—*Pterygometopus jukesi* (v.c.), *Chasmops*, *Plectorthis* (very large) (v. abt.), *Harknessella* aff. *bilobata* (v. abt.), *Dalmanella* (very large sp. of *canalis* group) (c.), *Nicolella actoniae* (c.), *Plectambonites* sp. This horizon, according to Dr. Elles, is succeeded by some 20 feet of calcareous ashy mudstone beneath the Rhiwlas.

The succession south of Moel Fryn is confirmed by that at Gelli grin, which is as follows :—

Pont y Ceunant Ash.

Gap, say, 6 feet.

Plectambonites rhombica—Harknessella Beds.

10 b. Coarse ash. *Harknessella* (v. abt.), *Cliftonia* sp. *D.* var. (abt.), *C.* sp., *Plectambonites rhombica* (abt.).

Gap, say, 3 feet.

10 c. Ash. *Harknessella* (v. abt.), *Nicolella actoniae*, *Cliftonia* sp. *D.* (v.c.), *C.* sp., *Plectambonites rhombica* (abt.), *Leptaena* aff. sp. *G.*

Gap, say, 4 feet.

10 d. Bed with *Nicolella actoniae* and *Cliftonia* sp. *D.* var.

Platystrophia Beds.

10 e 1. Ash. *Platylichas laxatus* (c.), *Calymene*, *Cybele*, *Dalmanella* (S.L.) sp. *E.* (c.), *Plectorthis* sp. *A.* (c.), *Harknessella* (r.), *Nicolella actoniae*, *Platystrophia* (c.), *Cliftonia* sp. *D.* (v.c.), *C.* sp., *Plectambonites rhombica* (v.c.), *P.* sm. sp., *Leptaena* sp. *G.* (v. c.).

Gap to 10 g about 4 feet. Between these horizons but out of the line of section some beds with *Cryptolithus* and "*Acaste*" *apiculata*.

Strophomena aff. *grandis* Beds.

10 g. Blue mudstone. In the upper part: *Cryptolithus, Calymene, Brongniartella,* "*Acaste*" *apiculata, Dalmanella* sp., *D.* sp. (coarse-ribbed form) (v.c.), *Cliftonia* sp. *A.*, *Strophomena* aff. *grandis*, geniculate Rafinesquinid, *Plectambonites* (*soudleyensis* type), *P.* aff. 5-*costata*. This horizon is succeeded by a foot or so of ash with abundant Dalmanellids. It contains the fauna of the mudstone overlying the Pont y Ceunant Ash in Y Garnedd quarry.

Gap, say, 15 feet.

10 h. Ash with Rafinesquinid-K. sp. *A.* c. 9 feet.

Leptaena H.—*Platylichas* Beds.

The following near the base:—

Dalmanella (*canalis* group) (abt.), "*Dalmanella*" sp., *Nicolella actoniae* (c.).

Near the summit:—

Platylichas, Calymene, Brongniartella, "*Acaste*" *apiculata, Dalmanella* (*canalis* group) (v.c.), *Nicolella actoniae* (c.), *Plectambonites* sp.

Gap, say, 5 feet.

10 i. Ash. *Platylichas laxatus* (c.), *Brongniartella, Dalmanella* (*canalis* group) (v.c.), "*Dalmanella*" sp., *Plectorthis* (c.), *Plectambonites* sp.

Gap, say, 20 feet.

Crystalline limestone (few feet) with abundant *Nicolella actoniae.*

Harknessella aff. *bilobate* Beds.

Mudstones and ashy beds, say, 15 feet, but probably very variable. Includes two horizons: (*a*) (in old quarry 1,100 feet west of the farm) 2 feet to 3 feet above limestone a large geniculate Rafinesquinid (abt.).

Pterygometopus horizon.

(*b*) 4 feet to 6 feet above (*a*), and in the main section: *Pterygometopus jukesi* (v.c.), *Chasmops, Dalmanella* (v. large sp. of *canalis* group), *Plectorthis* (large) (abt.), *Harknessella* aff. *bilobata* (v.c.), *Nicolella actoniae* (c), *Plectambonites* Rafinesquinid-K. sp.

The succession of faunas compares closely with that at Maes meillion, and shows quite clearly that the *Dinorthis* horizon at Cerrig y gath is below the Pont y Ceunant Ash horizon and therefore referable to the Allt ddu Mudstone. The crystalline limestone with *Nicolella actoniae* again occurs near the top. Moreover, it is succeeded as at Moel Fryn by the bed with *Pterygometopus.*

At Creigiau Bychain, east of Llangower, the succession to the north-west of the Rhiwlas outlier is preserved as follows:—

Base of hill to 16 e. Mudstones, poorly fossiliferous.

Dinorthis flabellulum horizon.

16 e. Mudstone. *Dalmanella* sp., *Harknessella* (c.), *Dinorthis flabellulum* (abt.), *Cliftonia, Cryptolithus* sp.

Gap, say, 10 feet.

Cryptolithus sp. *A.* horizon.	16 f. Mudstone. *Cryptolithus* sp. *A.*, *Brongniartella*, *Dalmanella* (small) (r.), *Harknessella* (abt.), *Cliftonia*.
Hiatus.	Gap, say, 10 feet.
Strophomena aff. *grandis* horizon.	16 g. Blue mudstone. *Dalmanella* (10 g form or aff.) (abt.), "*Dalmanella*" sp. (v.c.), *Cliftonia* sp. *A.* or aff. sp. *A.*, *Plectambonites* (*soudleyensis* type) (c.).
	Gap, say, 7 feet.
	16 h. Small exposure with *Cliftonia* cf. sp. *A.*
	Gap, say, 3 feet.
	Rhiwlas scarp.

Here the Rhiwlas Beds rest within a few feet of the *Strophomena* aff. *grandis* horizon, which elsewhere, as at Gelli grin and Maes meillion, occurs a considerable distance down in the succession.

Again on the north-east and east of the outlier the Rhiwlas rests on some 15 ft. of ashy mudstones with an abundance of *Cryptolithus gibbifrons*, *Cliftonia*, *Plectorthis*, *Nicolella actoniae*, *Leptaena H.* and other geniculate Rafinesquinids. *Brongniartella* and *Calymene* occur, and the higher layers contain phosphatic nodules. The position of these beds is manifestly between the *Leptaena H.*—*Platylichas* Beds and the *Harknessella* aff. *bilobata* horizon, and corresponds to the gap in the other sections (Fig. 1).

If the sections in which the limestone with *Nicolella actoniae* is present are compared, it will be found that the limestone occurs at the same faunal level, but that where, as at Creigiau Bychain, the limestone is absent, the fauna of the beds underlying the Rhiwlas proves them to be below the limestone horizon, and their position can be precisely specified by reference to the sections where the Limestone occurs.

These observations are inconsistent with the occurrence of the limestone at different horizons, and the lenticular nature of that rock cannot be assumed.

Since the limestone thus appears to occupy the same position in the faunal sequence, its absence in some places, together with the fact that the Rhiwlas is in contact with different faunal horizons, strongly suggests an unconformity at the base of the Rhiwlas. Such an unconformity can be demonstrated at Creigiau Bychain.

Referring to Fig. 2, a small exposure of *Strophomena* aff. *grandis* Beds is seen at the point A, about 33 yards from the Rhiwlas scarp. Two intervening exposures occur, one at B with "*Acaste*" *apiculata*, *Platylichas*, *Dalmanella* and *Plectorthis*, and certainly referable to the *Platylichas*—*Leptaena H.* Beds or the beds below, the other at C with abundant *Plectorthis* and *Nicolella actomiae*, and referable to a horizon in the *Leptaena H.* Beds, probably above the *Platylichas* horizon.

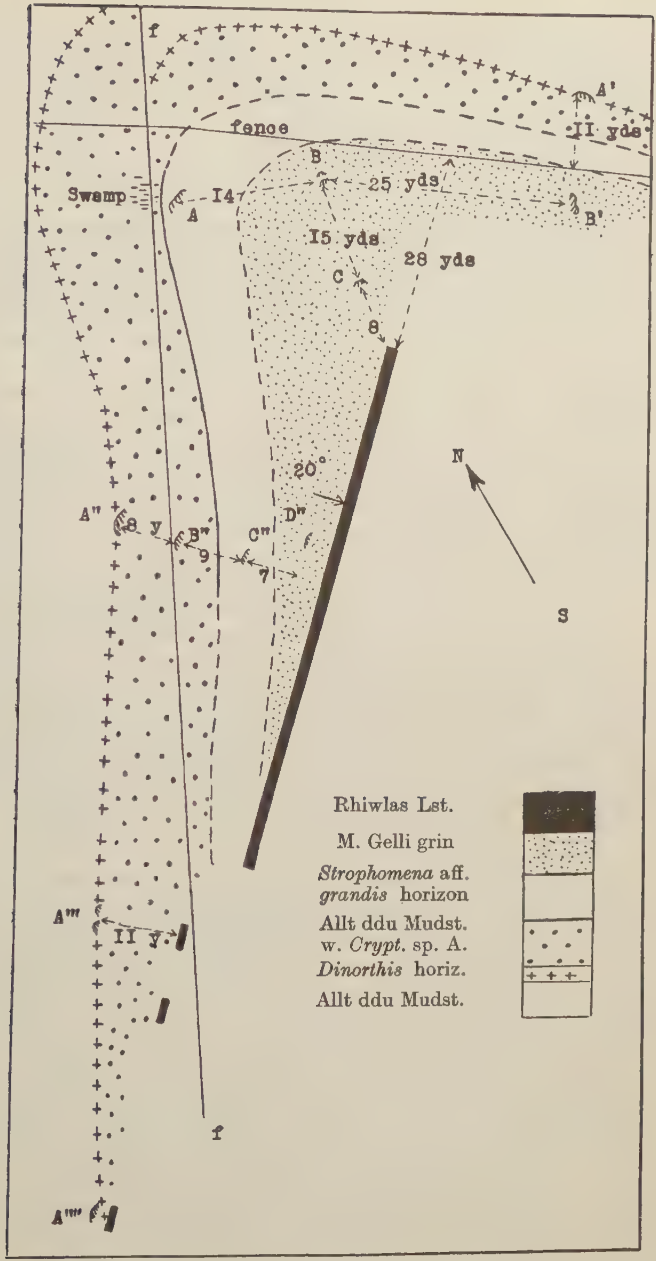

FIG. 2.—Sketch-map of north-west side of the Rhiwlas Outlier on Creigiau Bychain. (All distances save those specified are grossly approximate.)

In the second traverse, a series of scarps of Allt ddu Mudstone are succeeded at A″ by the *Dinorthis flabellulum* horizon with the usual fossils, and this is followed at B″ by the *Cryptolithus* sp. *A.* Beds. The next exposure C″ yields the fauna of the *Strophomena* aff. *grandis* horizon, and at D″, only 3½ yards from the Rhiwlas scarp, the beds again yield an abundance of *Cliftonia*, and in the absence of abundant trilobites are referred to a horizon below that with *Platylichas*.

Still further south *Dinorthis* again occurs in abundance at A‴, separated by only 11 yards from the Rhiwlas scarp, and some 30 yards south of this point the Rhiwlas Limestone is in contact with Allt ddu Mudstone, which as the above fossils are not found is presumed to represent a horizon below that of the *Dinorthis* Bed.

Now in the absence of a serious fault, the above sections afford a clear demonstration of unconformity at the base of the Rhiwlas. That a fault does intersect the sections is evident from the slight displacement of the Rhiwlas scarp in the A″ traverse, but this is manifestly of negligible character, as may be inferred from the normal faunal succession in the Allt ddu and Gelli grin. It was with a view to illustrating this fact that I have dealt at some length with the sequence in the other localities.

There remains one point to discuss. It will be seen that on the west side of the hill Dr. Elles has shown the Rhiwlas Beds in contact with a good band of Gelli grin, and it is clear that the *Dinorthis* horizon is included in that series. If, however, the *Dinorthis* horizon is assigned, as it should be, to the Allt ddu, the unconformity would have been obvious in the absence of faulting. Apart from the other evidences I have adduced, the assumption that the *Dinorthis* beds at Creigiau Bychain are of Gelli grin age involves the repetition in the vertical succession of a sequence of three successive faunas—a notion that can hardly commend itself to a stratigrapher.

The probable General Nature of the Disturbance.

The presence of a well-defined unconformity at the base of the Ashgillian in Pembrokeshire (3), the unconformity at the same horizon in the Bala area, and the discordance at the summit of the *Pleurograptus linearis* zone in the Central Belt of South Scotland (vide Troedsen), suggest an enquiry as to how far the disturbance at that horizon may be of a general character; but apart from these areas the published faunal evidences are too slender to permit of demonstration.

In the Glyn Ceiriog area Groom and Lake demonstrated a hiatus between the Ddolhir Beds and the Caradocian, a hiatus which was shown to be filled by the Blaen-y-cwm and Ty'n-y-twmpath Beds further west. The explanation offered by Groom and Lake, and restated by Wills and Smith (4), is as follows: "The complete sequence is developed at most places west of Gelli, but east of that place the rapid diminution in thickness of the Ddolhir Beds proper and the absence of the Ty'n-y-twmpath and Blaen-y-cwm Beds are best explained by faulting along a gently dipping plane." Subsequently, however, these authors have so far modified their view as to assert that the magnitude and effects of the Ddolhir fault were overestimated, and they propose as a possible explanation a non-sequence or unconformity east of Glyn Ceiriog (5). Now, where such a disturbance has been demonstrated in three remote areas, and is a possible explanation of a physical discordance observed in a fourth, and in the absence of contrary and decisive evidence relating to the junction in other areas, I shall not hesitate to suggest that the unconformity is of general occurrence.

The Breaks in the Gelli Grin Series.

To the east of the Caledonian trend-line passing through Rhos y gwaliau and Caer-hafotty farm, the Pont y Ceunant Ash horizon is everywhere succeeded by the beds with *Plectambonites rhombica*, and these in turn by the *Platystrophia* Beds. To the west of this line, whether at Creigiau Bychain or Y Garnedd, neither of these horizons is present, and it is the *Strophomena* aff. *grandis* Beds that rest upon the Ash. There is thus a break involving the absence of the lower 25 feet of the Gelli grin Ash Series.

The *Strophomena* aff. *grandis* Beds and higher horizons as far as the base of the Limestone are represented in or near all lines of section in the area and wherever higher horizons are present, so that their absence is probably due to removal after the deposition (and removal) of the limestone. It is also true of the limestone and the succeeding beds that, whilst they are frequently absent, there is no definite evidence of considerable erosion prior to the deposition of the highest of these beds. Nevertheless, the nature of these deposits, as also the apparent absence locally of certain faunal horizons, points to local breaks and hiati of a more general character and it must be borne in mind that whilst the latter are not evident from the table, and in no way affect this discussion, their magnitude may exceed that of the known hiati.

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Shugo: A Mud-Volcano in the Western Caucasus. With a theory of the origin of mud-volcanoes and their significance with regard to oil-production.

By Felix Oswald, D.Sc., F.G.S.

(PLATE XXI.)

In the summer of 1915 I had occasion to visit some of the oilfields of the Western Caucasus, with the view of locating new oil-wells. During my study of the geology of the petroliferous areas on the northern slope of the Caucasus I was able to ride to the Shugo crater, the easternmost of the mud-volcanoes of the Taman peninsula. This crater is situated on the watershed between the Shugo and Chekups Rivers, about five miles south-west of the village Varennikovsk. From a distance, as I rode uphill from the wide, alluvial plain of the Kuban River, the picturesque and well-wooded foothills did not disclose any semblance of a mud-volcano, but on climbing the southern slope of the hill, a most unsuspected and striking view was suddenly revealed. Here at my feet lay a nearly perfect crater, about ¾ mile in diameter (Pl. XXI, Fig. 1).

The high crater-wall is a nearly complete ring, breached only on the north-east, where the liquid mud has been able to escape down the valley in a stream 30 or 40 feet in width, widening out towards the Kuban plain. The outer slopes of the hill, thickly clothed in oak-scrub and luxuriant undergrowth, form a striking contrast to the interior of the crater, which consists of a rough and broken area of barren, grey mud, devoid of vegetation, and bleached white by the strong sunlight of these latitudes so as to dazzle the eyes as much as if it were a snowfield. The circular character of the crater is suggestive of its origin by a violent explosion.

The emission of gas, salt water and mud takes place from many points, but the chief focus of activity lies in the actual centre of the crater, where gas issues from two apertures on a low dome of mud (Pl. XXI, Fig. 2). Here gas is emitted fairly frequently, pushing up large clods of cold mud of the consistency of dough. Cold salt water also wells up and forms large pools round this central dome. A more violent and explosive action is visible in the south-west part of the crater; here there are many small craters and cones of varied shape and form, some dome-shaped, some sharply conical (Pl. XXI, Fig. 3). Every few minutes there was a loud noise, like a hoarse cough, almost at my feet, followed by a violent shower of mud and stones, hurled up to a height of sometimes twenty feet. The subterranean noises immediately preceding an eruption are certainly weird enough to justify the belief held by the local Cossacks that the place is haunted, and nothing will induce them to visit it after dark.

All stages of activity of a mud-volcano are exhibited by these minor cones. From some of them salt water flows out quietly, from others gas issues, either gently, slowly heaving up mud, or with ever-increasing violence until it culminates in a paroxysmal eruption of stones and mud. The gas has been analysed by Baraboshkin, and consists mainly of marsh-gas, 93·2%, which preponderates, as in all the Caucasian mud-volcanoes. It sometimes takes fire, probably due to sparks caused by the friction of stones and pyrites during an eruption. The subjoined table gives a useful comparison with the results of older analyses :—

ANALYSES OF GAS FROM MUD-VOLCANOES OF THE CAUCASUS.

	Gnilaya.	Shugo.	Pekla (on Azov Sea).	Baladjary	Kobi.	Marazinsk.	On Apsheron peninsula.	Titanovka.	Selena-Gora.
CO_2 . .	26·7	6·7	3·1	0·2	4·8	4·8	2·18	3·5	4·44
CO . .	0·8	—	0·2	1·0	0·6	1·2	—	—	—
CH_4 . .	72·5	93·2	87·5	80·6	54·3	81·6	93·09	92·24	95·56
C_nH_n .	—	—	—	—	—	—	3·26	4·26	—
Heavy hydrocarbons .	—	—	—	—	3·7	—	—	—	—
O .	—	—	0·9	2·0	0·8	1·0	—	—	—
H . .	—	—	—	10·2	—	—	—	—	—
N . .	—	—	8·3	6·0	40·25	10·4	0·49	—	—
H_2S . .	trace	trace	trace	trace	0·25	trace	—	—	—
PH_3 . .	—	—	—	—	—	trace	—	—	—
	100	99·9	100	100	104·7	99	99·02	100	100
Analyses by	Baraboshkin			Kharichkov			C. Schmidt	R. Bunsen	

In the gas of the Marazinsk mud-volcano phosphoretted hydrogen has been detected, which would, of course, ignite spontaneously on eruption.

It is evident that whilst the mud dries quickly on the surface and becomes traversed by a network of cracks, it remains liquid for a considerable time below its crust, and I had to walk as delicately as Agag over the treacherous surface, which undulates in a most disconcerting manner. Indeed, great caution is necessary to avoid treading on any damp patch, which would entail a speedy and rather disagreeable end by suffocation in liquid mud.

At the time of my visit (1915) the Shugo mud-volcano was passing through a period of comparative quiescence, but only five or six years previously there had been such a violent outburst that the gas took fire and burned for several weeks on end. It was at this period that so much mud was discharged as to breach the crater on the north-east and to form a wide stream, which (as already mentioned) flowed through the gap in the crater-wall.

In general, mud-volcanoes are subject to occasional, very violent paroxysms, occurring at long intervals of time ; for both at Temriuk, in the Western Caucasus, and at Lok Botan, near Baku, in the Eastern

Caucasus, highly explosive eruptions have been recorded, accompanied by flames from ignited gas, and the débris was ejected to considerable heights. The same alternation of paroxysmal outbursts and comparative quiescence is well marked in the Burmese mud-volcanoes of the Arrakan Range and Ramri Island.[1]

Thus at Temriuk, only a few miles to the west of Shugo, Abich records a great eruption in 1844, when a column of fire rose to a great height, accompanied by a thunderous noise, and a vast amount of débris was ejected, the fragments being often nearly a metre in thickness, and wide streams of mud flowed a considerable distance to the north and north-west.

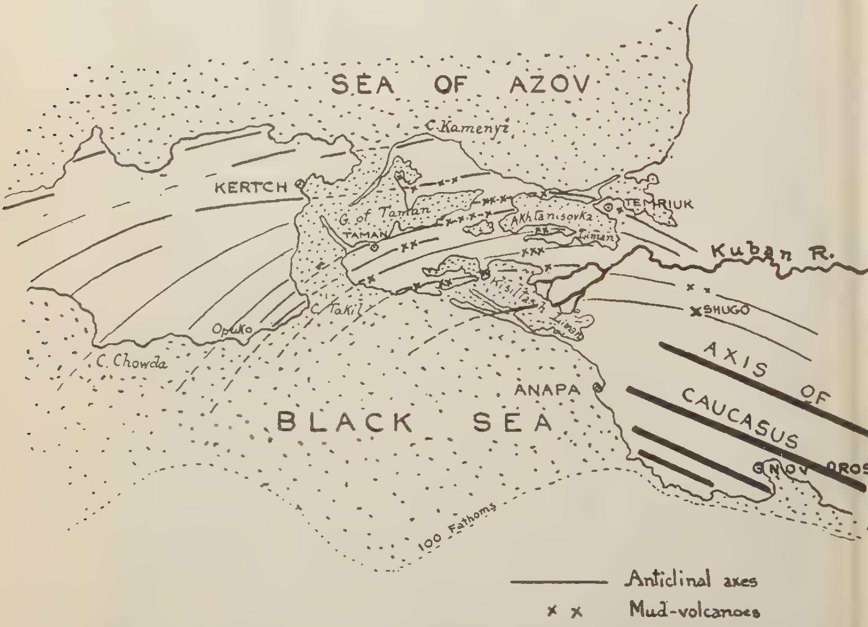

FIG. 1.—Diagram of the Late-Tertiary folds of Kertch and Taman, partly after Andrussov.

At Lok Botan, near Baku, Sjögren[2] has recorded in great detail a similar explosive eruption in 1887, when sheets of flame rose up to 600 metres; and an earlier paroxysm took place in 1864. In Burma, at Kyauk Phyu on Ramri Island, similar violent eruptions

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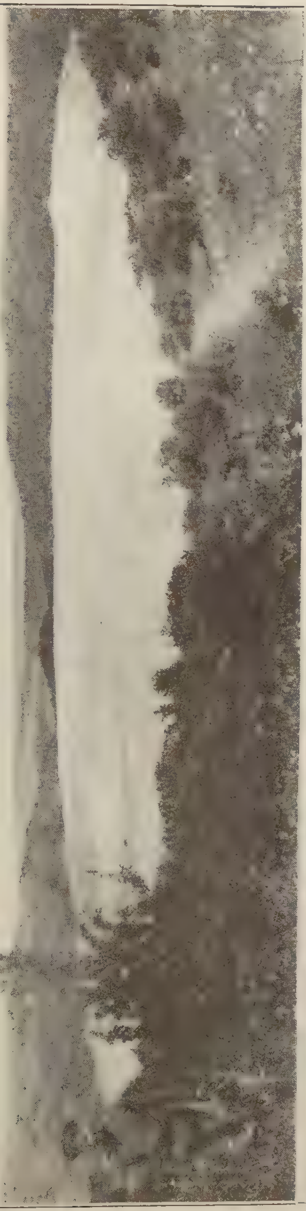
[1] F. R. Mallet, "Mud-volcanoes of Ramri and Cheduba," *Rec. Geol. Surv. India*, xi, 188; and Pascoe, "Petroleum Occurrences of Assam and Bengal," *Mem. Geol. Surv. India*, xl, 315.

[2] *Jahrb. k. geol. Reichsanst.*, 1887, Bd. 37, Hft. 2.



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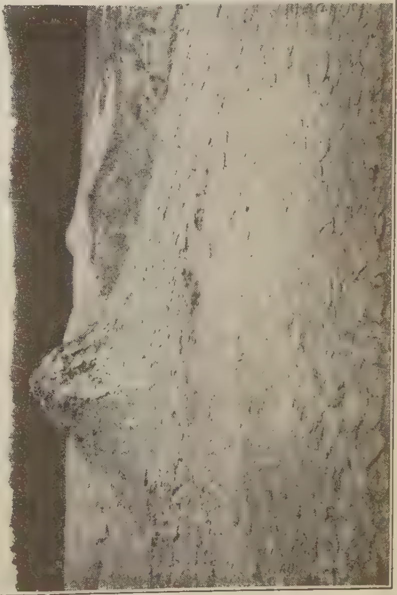

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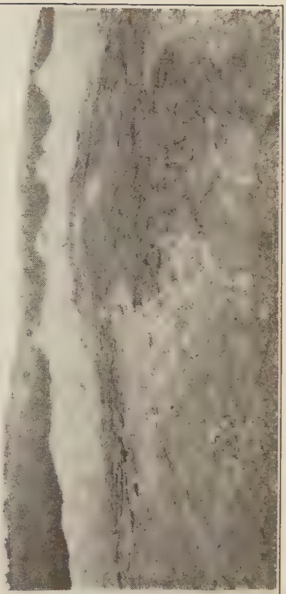

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FIG. 1.—INTERIOR OF CRATER OF SHUGO MUD-VOLCANO, LOOKING TO N.E. FIG. 2.—CENTRAL PART OF CRATER WITH CONES AND RECENT EMISSION OF MUD. FIG. 3.—CONES IN S.W. PART OF CRATER.

have been observed, with flames lighting up the country for miles round, especially in 1833 and 1843.[1]

With regard to the nature of the ejectamenta of the Shugo mud-volcano, the light grey mud consists mainly of débris from Late-Tertiary strata, especially the grey, sandy clays of the Pontic beds, grey clays and limestones of the Maeotic beds, grey clays of the Sarmatian series and of the underlying *Spaniodont* beds, the clays and limestones of the *Spirialis* beds and Chokrak limestones belonging to the Mediterranean Beds, and the clays of the Foraminiferal series in the Oligocene. Fragments of older beds also occur, though more rarely, such as Eocene micaceous sandstones, Senonian white marls with fucoids, brecciated ironstones of the Lower Cretaceous, Valanginian coral-limestones, etc.[2] It is probable, however, that these fragments are not derived directly from the older beds, but from later conglomerates of Miocene or even Pliocene age. For instance, in the Abinsk and Gelenjik areas the Nadrudny series of Pliocene age contain pebble-beds of Lower Tertiary and Cretaceous rocks, and in the Krimsky area Pontic beds contain detrital limestones with large pebbles derived from earlier strata.

The mud-volcanoes of the Taman peninsula are ranged on the summits of anticlines of Late-Tertiary beds. These anticlinal folds curve round from the normal S.E.–N.W. strike of the Caucasus to the N.E.–S.W. direction of the Crimea. They are, however, not continuous with the Crimean folds, but lie in front and to the south of them (Text-fig. 1, Map of the Taman Tertiary folds, modified after Andrussov). This circumstance is suggestive and is favourable to my hypothesis that when the folding of the Late-Tertiary strata took place, the Crimea (which Suess was the first to recognize as a "*Horst*") acted as a resistant mass to the force proceeding from the south, and caused the Tertiary folds to bend round to the south-west. Similarly, at the east end of the Caucasus the bending-round of the Tertiary folds from a S.E. to a S.S.E. and finally to a southerly direction (Text-fig. 2, Map of the East Caucasus Tertiary folds) forms a strong presumption that a similar resistant horst occurred in the area of the Caspian Sea and that this horst subsequently sank beneath its waters.

It is a highly significant fact that the mud-volcanoes of the Caucasus only occur at its eastern and western extremities, where the Tertiary folds have been deflected from the normal N.W.–S.E. direction of the Caucasus. In the Maikop and Grosny oilfields, situated on the northern flank of the range, where the folds preserve this normal direction, no mud-volcanoes are present.

Now if continued mountain-pressure is exerted upon concave folds, when the strata are no longer plastic enough to be folded any more, fractures would inevitably be formed transverse to the axis of folding, and I would therefore suggest that owing to such torsional fractures the oil stored up in the anticlinal domes escaped along these fractures, passing either right to the surface or laterally into porous Pliocene and Recent beds, as on the hills Borisa and Glievka in the Taman peninsula, where beds of oilsand occur in the Pliocene Nadrudny beds and even in post-Pliocene strata, where the occurrence is clearly secondary. Finally, mud-volcanoes would mark the last stage of the process, when only gas and saline water remained in the anticlinal domes. The normal gentle emission of gas and water probably indicates that the transverse fissures are just kept open, whilst the occasional explosive eruptions would be due to these fissures closing up for a time, until the pressure of the gas became too great, only to be relieved by a violent paroxysm with explosions of gas, hurling detritus into the air. It is noteworthy that at Lok Botan Sjögren[1] was able to observe that faulting was

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[1] Mallet, op. cit., 197.

[2] Prokopov, K., *Mém. Com. Géol.*, xcii, 92 (in Russian).

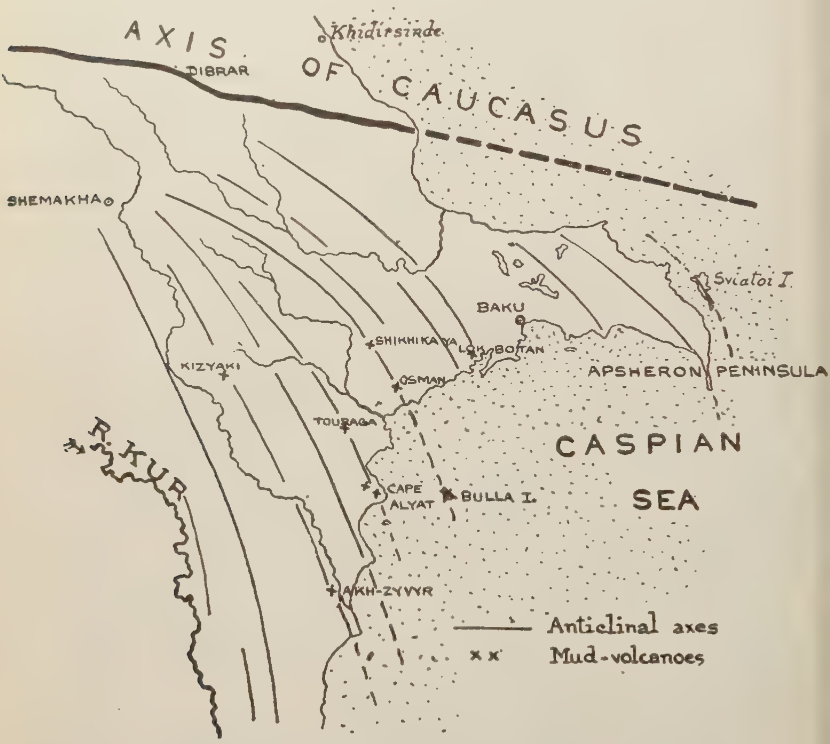

FIG. 2.—Diagram of the Late-Tertiary folds of the Eastern Caucasus.

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[1] Op cit., 235.

still in progress and had taken place even since the 1864 eruption, whilst in some cases fissures still remained open.

At Shugo no trace of petroleum could be observed, and in other mud-volcanoes traces of oil are never more than slight, as at Temriuk and Tsymbaly, so that any oil in the anticlinal folds must have long ago been exhausted, only leaving gas to be given off, just as in exhausted oil-wells, a fact very noticeable on the Maikop and Krimskaya oilfields. A notable instance of this emission of gas after the total exhaustion of an oilwell is furnished by a well at Maikop (Shirvansky : No. 2 on plot 457) which fountained in March, 1915, giving a production of 30,000 poods of oil a day in April, though much had run to waste. This production decreased gradually and ceased in February, 1926 ; only gas was then emitted. In an extinct mud-volcano near the Shugo crater, on the heights between the rivers Psebeps and Shugo, the final stage of exhaustion is reached by the emission of springs with sulphuretted hydrogen.

If this view is correct, it follows that the presence of mud-volcanoes would not be a favourable indication for the successful exploitation for oil in their close proximity, for the oil originally stored up in the anticlines would, on this theory, have disappeared long ago through the transverse fissures caused by a torsion of the folds. Yet on the other hand oil may still be abundant in adjacent anticlines which have been unaffected by torsion, as at Baku, which lies just to the north of the main belt of mud-volcanoes in the Eastern Caucasus. But neither in the area of the Taman mud-volcanoes nor in the immediate proximity of the mud-volcanoes of the Eastern Caucasus has any considerable find of oil been established.

Finally, as a confirmation of my theory, attention may be drawn to the fact that in the area of the Burmese mud-volcanoes, which (as in the Caucasus) are ranged along the summits of anticlines, the folds have also been bent and twisted, especially on Ramri Island, where the sinuous course of the folds is strongly marked. This is probably due, as Pascoe[1] observes, to the "interference of a system of folds more or less transverse to the predominant system." Thus the direction of the anticlinal folds "swings round northwards from the Arakan coast and Chittagong, where it is N.N.W.–S.S.E., to N.N.E.–S.S.W. in Kachar and the Mikir hills." It would seem to be something more than a mere coincidence that in both the Burmese and the Caucasian areas mud-volcanoes have only arisen where the Tertiary oil-bearing folds have undergone torsion, resulting in transverse fissures. It may also be mentioned that the mud-volcanoes of Trinidad are distributed along important fracture-lines developed as a result of anticlinal faulting, especially in pitching structures.

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[1] Op cit., xl, 315.

Petrographic Notes on Three Rock-types from the Shetland Islands.

By F. Coles Phillips, M.A., Ph.D., F.G.S., Fellow of Corpus Christi College, Cambridge.

(PLATES XXII AND XXIII.)

THREE years ago the author commenced petrological work in the Shetland Islands, and two communications dealing with different rock-groups have been published (Phillips, 1926, 1927). The work was undertaken as a subject for a degree thesis in the University of Cambridge, and the thesis as presented deals also with other rock-groups on which no published work exists. As it seems unlikely that the author's work will be continued, it has been deemed of interest to publish the following notes, incomplete though they may be.

1. Epidote-bearing Granite.

Earlier than the igneous rocks of Old Red Sandstone age, a number of intrusions of variable character were forced in amongst the already-metamorphosed schists and gneisses. Petrographically, they show considerable variation, and in some instances are best described as intrusive complexes. They are probably also of more than one age, having suffered to very varying degrees from dynamic metamorphism. One such intrusion cuts across Mainland from Aith Voe to Bixter Voe and Kirka Ness, following closely the direction of the line of faulting bounding the Walls syncline of metamorphosed O.R.S. sediments from the gneisses and schists of central Mainland. Its apparent continuation forms the now isolated islands of Hildasay, Cheynies, Oxna, and Papa.

Very little has been written about this intrusion; it was described by Hibbert as "epidotic syenite", and is so referred to by later writers. Slices from the island of Hildasay, originally in the collection of Sir J. J. H. Teall, and now in the cabinets of the Sedgwick Museum, display features of special interest. The rock is a much-altered biotite-granite, with abundant quartz and extremely pleochroic greenish-brown biotite, in which the absorption for light vibrating parallel to the cleavage is almost complete. The original felspar of the granite is completely altered to a meshwork of elongated crystals of white mica, disposed in the interstices of which are small amounts of water-clear albite. There is a certain amount of fresh felspar of a later generation; the refractive index is lower than that of Canada balsam, and multiple twinning is present. In some cases this bears a very close resemblance to the cross-hatching of potash-microcline, but in others it is discernible as albite, Carlsbad and pericline twinning developed together.

The epidote minerals are present in three different forms, apparently representing successive generations. *Allanite* occurs in crystals elongated parallel to the diad axis, and attaining a length of 2 mm.

It shows a zonary growth, sometimes visible in ordinary light and in any case rendered very evident by the variable extinction between crossed nicols. The mineral is moderately pleochroic in shades of brownish-green, and has a low double refraction. The optical sign is negative. As is frequently the case with allanite in granitic rocks, it is surrounded by an *almost colourless epidote,* with similar crystallographic orientation, although the optical orientations in the two minerals do not coincide. A similar almost colourless epidote occurs also in very irregularly-outlined crystals with a corroded aspect, a single irregular crystal and several surrounding patches isolated from it in the thin slice having uniform extinction. The third stage of crystallization of epidote is indicated by fringes of *grass-green epidote,* strongly pleochroic, grown around the paler-coloured mineral. This latest generation is much less fresh, contains more inclusions and has an appreciably different double refraction. It is in most cases, however, grown in optical continuity with the earlier material, twin-planes in the latter frequently extending through the coloured fringe. Whilst, however, the colourless core shows good crystal outline against the outer fringe, this latter presents on the outside of the complete crystal very irregular outlines. The dark brown biotite seems in several cases to be moulded around even the latest-formed epidote.

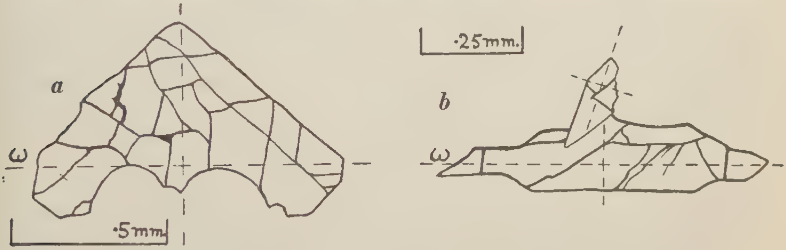


FIG. 1.—Accessory mineral of epidote-bearing granite, Hildasay, Shetland. *a.* Section highly inclined to the optic axis. *b.* Section of a twin-crystal, approximately parallel to the optic axis.

Associated with many of the epidote-biotite aggregates, and extending outwards into the surrounding areas of clear quartz, are feathery groups of acicular crystals of pale greenish pleochroic amphibole. Several accessories are present; apatite builds stout prisms of early formation; the opaque mineral, present in small amount in idiomorphic crystals, is pyrites. An accessory of some interest shows small diamond-shaped sections enclosed in pale epidote, with occasional larger crystals attaining nearly 1 mm. in length. The forms present are very flattened tetragonal bi-pyramids (Fig. 1); the refractive index is high, double refraction very high, and optical sign positive. Dichroism is marked :—

o brown-yellow,
e reddish-brown,

and absorption *e* greater than *o*. The flattened pyramidal form causes elongation in a vertical section at right-angles to the optic axis, so that the sign of the elongation is negative. One vertical section shows the presence of the characteristic elbow-twin of this type of tetragonal mineral. These are diagnostic features of xenotime (and " hussakite "), whose usual occurrence is in granitic rocks; it may be noted that in the Shetland rock the presence of rare earths is indicated by the development of allanite, and the presence of sulphur by the fact that the opaque mineral is pyrites.

A considerable literature has grown up around the question of the primary or secondary origin of epidote in granitic rocks (Butler, 1909, with earlier references). Hobbs (1889) dealing with the Ilchester granite concluded that the allanite was undoubtedly primary, but that there was evidence that the formation of epidote was due to pressure-metamorphism. Keyes (1893) concluded from a study of the Maryland granites that the association of allanite and epidote was so intimate that in some cases at least both minerals were primary constituents. Turner (1899) described alkaline granites from the Sierra Nevada, in which epidote " wedged in between the other constituents, all of which are fresh " is probably primary. The granite in question, however, becomes richer in lime towards its marginal contact with the slates.

I am indebted to Dr. A. Harker for drawing my attention to a very interesting occurrence of epidote-bearing granitic rocks in British Guiana. The fullest published account of the geology of this area is that given by J. B. Harrison in his book on the goldfields (1908). There is not much detailed petrological work in this account, but a large amount of his material was subsequently bequeathed by him to the Sedgwick Museum. Many of the granitic intrusions have undergone dynamic metamorphism, and are now in the state of epidotic gneisses. In a considerable number of cases, however, the presence of clear granular epidote in a very fresh felspathic rock of igneous aspect leaves little room for doubt that this mineral has here crystallized directly from the melt. Slices from Kartuari Rock, Mazaruni River (23807) and Waini Creek (23379) closely resemble the Shetland rocks. One generation of felspar is much sericitized, but there is abundant fresh microcline. A slice from south of Monkey Jump, Essequibo River (23976) shows well-crystallized green hornblende later than, and accompanying, the biotite, and in 23483 from the Kettle Rapids, Cuyuni River, abundant granular epidote is the only dark mineral in a felspathic matrix of aplitic texture. This type of rock is presumably the product of a slightly later stage of crystallization than the granites with altered plagioclase, in which the epidote is often more abundant along fissures than in the body of the rock. In some of the slices xenotime is a prominent accessory (23976, 23807). It often has a deceptive resemblance to sphene, but the perfection of the (110) cleavage is noticeable in sections nearly parallel to the base, and these same sections yield a good positive uniaxial optic picture.

Recently Duparc (1922) has described from S. Ural a plagioclase-biotite granite developed within a vast granitic region of very acid type, with white mica, acid oligoclase, orthoclase, microline and quartz. The plagioclase in the epidote-bearing biotite-granites is Ab_3An_1, twinned on albite and pericline laws and remarkably fresh. The abundant epidote occurs in corroded skeletal crystals, which, however, appeared before the biotite. Duparc considers two possible origins; either the epidote is a normal primary constituent, consolidated between the accessories and the biotite and later resorbed, or else it is a foreign mineral belonging to an epidotic rock absorbed by the granite. He believes that the available evidence accords better with this latter alternative.

The Shetland occurrence presents many points of similarity with that of S. Ural. The granite in question contains biotite as the chief ferromagnesian, and the fresh felspar is acid plagioclase; many of the neighbouring intrusions are very acid granites with abundant muscovite. The mode of its occurrence and the association with xenotime indicate that the allanite separated as a primary constituent from the original granitic magma. The formation of the other varieties of epidote belongs to a later stage, involving the destruction of the felspars of earlier crystallization, the formation of biotite and finally of amphibole (indicating falling temperature and increasing concentration of water) and the crystallization of a new generation of plagioclase. The source of the introduced iron and calcium cannot be definitely indicated, but one may tentatively follow Duparc in suggesting that the corroded crystals of pale epidote suggest derivation by absorption of material from some outside source.

The petrographical features of this Shetland granite may afford suggestive evidence in correlating with the intrusions in the mainland of Scotland to the south. Allanite and epidote in the Scottish granites have been described by Mackie and other authors, but there is evidence that in the newer granites epidote occurs only as a decomposition product. Mr. Barrow (personal communication) has pointed out to me that one of the most distinctive features of the older granites is the arrangement of the white mica in the decomposed felspars in sets of rigidly parallel laths, as compared with the finely-disseminated material in the cloudy oligoclases of the later intrusions. This feature he ascribes to the fact that the older intrusions were kept at a high temperature for a considerable period.

2. CHLORITOID-GARNET-ANDALUSITE SCHISTS.

The schists and paragneisses forming the major portion of the islands are in many places in a high grade of metamorphism, the development of staurolite and kyanite being common in several localities (Heddle, 1879, 1880). Of special interest are varieties carrying chloritoid. Heddle quotes two analyses of chloritoid from Hillswick Ness, where it occurs embedded in quartz in close association with kyanite and garnet, and mica-schists with chloritoid occur also in the south of Mainland. At Moo Wick, in Fetlar, there occur chloritoid schists containing garnet and andalusite. These rocks are in a hand-specimen reddish mottled with green. The porphyroblasts of chloritoid are easily discernible as black mica-like crystals with a hexagonal outline but superior hardness. In thin sections, the associates are seen to be muscovite and chlorite, with garnet, andalusite, magnetite, rutile and haematite. The chloritoid shows good basal cleavage and strong pleochroism :—

X green,
Y greenish-blue,
Z yellowish-green,

and the usual multiple lamellar twinning is present.

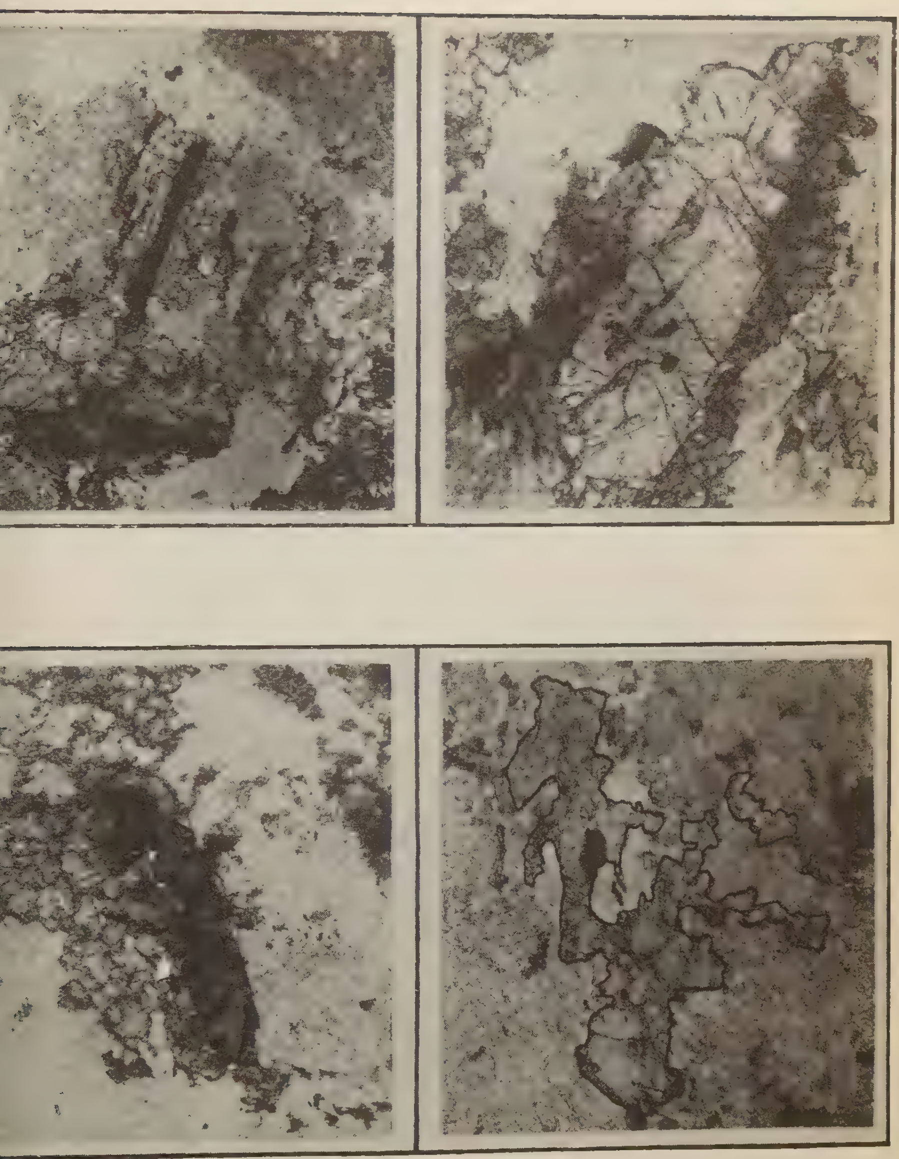
Some of the chloritoid was separated by the repeated use of methylene iodide, and an analysis of the material was carried out for the author. The excessive difficulty in bringing the material into solution makes the determination of the FeO evidently of doubtful accuracy, and the analysis is not here published ; it is sufficient, however, to show that the mineral agrees with a true chloritoid rather than with ottrelite in the ratio of SiO_2 to Al_2O_3. A bulk-analysis of the rock itself (I.) shows the high alumina and low lime content characteristically found in chloritoid schists.

	I.	II.
SiO_2	35·30	40·81
Al_2O_3	36·64	1·32
Fe_2O_3	2·87	2·46
FeO	7·58	·57
MgO	2·76	41·11
CaO	·84	·19
Na_2O	2·27	n.d.
K_2O	3·16	
H_2O +	5·60	13·21
H_2O −	·50	·82
CO_2	nt. fd.	nt. fd.
TiO_2	1·82	tr.
P_2O_5	·06	
MnO	·32	Cr_2O_3tr.
	99·72	100·49

I. Chloritoid-garnet-andalusite schist, Moo Wick, Fetlar. Anal. W. H. Herdsman.

II. Secondary serpentine, chromite quarries, Sobul, Unst. Anal. F. Coles Phillips.

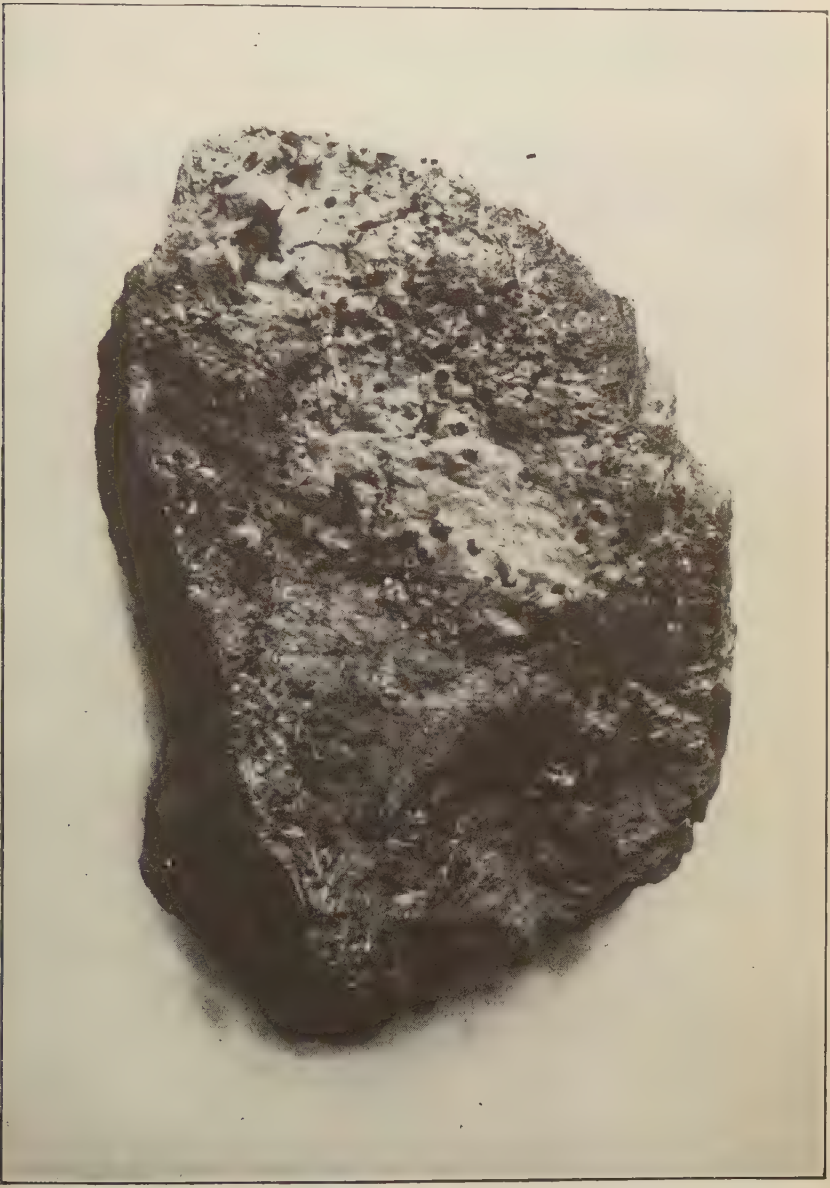
The andalusite is occasionally included in the chloritoid, but is usually present as small groups of grains in the micaceous groundmass, associated grains in a group being not quite in the same optical orientation (Fig. 2). These grains are irregular in outline, and surrounded by finely-divided white mica apparently derived from the andalusite. There is an appreciable yellow colour and pleochroism. Some of the mineral was separated by the use of bromoform and diluted methylene iodide and analysed qualitatively.



F. C. P. Photo.

Allanite, Epidote and Xenotime in Shetland Rocks.

[To face p. 504.



W. H. T. Photo.

HAND-SPECIMEN OF KAEMERERITE-SERPENTINE, UNST, SHETLAND ISLANDS.

Its composition was thus confirmed as essentially an aluminium silicate, with an appreciable manganese content; to this latter the colour and pleochroism are presumably due. Backström (1896) has described a manganandalusite with a content of nearly 7 per cent Mn_2O_3, with strong pleochroism :—

Z = a, Y = b blue green, tinged with grass-green,
X = c strongest absorption, intense pure yellow.

In the Shetland mineral, the optic axial angle is large, and the sign negative, the orientation being that of ordinary andalusite. The direction of strongest absorption, however, is not X, the pleochroism being :—

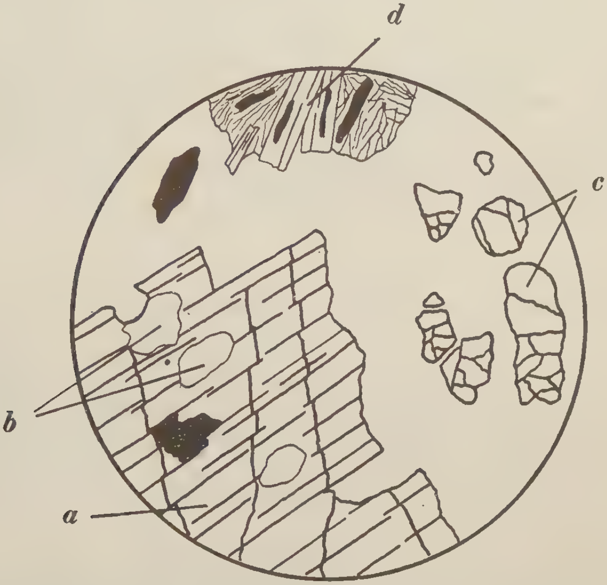


Fig. 2.—Diagram showing mineral relationships in chloritoid-andalusite schist Moo Wick, Fetlar, Shetland. *a*. Large platy crystal of chloritoid enclosing small areas of andalusite *b*. *c*. Fragments of partially altered andalusite in the ground-mass. *d*. Chlorite and well-developed white mica. The clear area is a ground-mass composed almost entirely of white mica in a very variable state of subdivision.

X, Y colourless or tinged with green,
Z very pale yellow.

Chloritoid-andalusite schists have recently been described from Australia by Tilley (1925), and resemble the Shetland rock in many respects. They are, however, much more highly siliceous, showing much free quartz, and do not contain garnet, though Tilley states that the stability field of chloritoid does extend up into the garnet zone. In the case of the Australian rocks, he has suggested that "andalusite developed at a stage corresponding to a maximum temperature of the sediments, and that chloritoid arose . . . at a period corresponding to increased shearing-stress and falling temperature, and partly at the expense of earlier formed andalusite" (op. cit., p. 313). For the special conditions of formation he has suggested the term piezocontact metamorphism.

In the Shetland rocks there is considerable evidence that similar conditions applied. The schists are associated with granitic intrusions more or less concordant with the foliation of the metamorphic rocks; and these intrusions are, like the schists themselves, rich in muscovite, suggesting a high water-content (cf. Tilley, op. cit., p. 312). The fact that the original andalusite of the high-temperature phase has been broken up into fragments not having similar orientations affords direct evidence that in the later stage of its history the rock was again subjected to stress-action, this stage corresponding to the abundant formation of chloritoid.

3. SECONDARY SERPENTINE.

The material to be described here has been previously figured and termed secondary serpentine (Phillips, 1927, pl. xlix, fig. 4, and p. 640). It is often the matrix of the well-formed crystals of chrome-chlorite to which a hydrothermal origin has been assigned, forming the lining of fissures in the serpentinized dunite in layers up to two centimetres in thickness. Having a hardness of about 3, and thus being easily cut with a knife, it is sometimes used by the islanders for shaping into small ornaments, and is usually termed by them "steatite".

A further physical and chemical investigation of the material has now been carried out. The colour is extremely variable, from a pale buff to apple-green or reddish-brown. The specific gravity of various samples varied from 2·44 to 2·55, and the average refractive index is 1·56. Thin slices show low double refraction, and either an obscurely fibrous structure or a radiating and spherulitic arrangement (fig., op. cit.). The analysis (II.) shows that it is a true serpentine, approximating in composition to the theoretical $3MgO.2SiO_2.2H_2O$, and certainly not related to steatite. The majority of the iron-content is reported as ferric oxide since every precaution during the analysis failed to yield a higher content of FeO than ·57 per cent, though on theoretical grounds it seems likely that the majority of the iron would be present in this latter form, partially replacing the MgO The mode of occurrence indicates the secondary origin of the material, and the association of the kaemmererite accords with a hydrothermal formation, but the low content of Al_2O_3 gives no information of the source of this component in the production of the chlorite.

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EXPLANATION OF PLATES XXII AND XXIII.

PLATE XXII.

FIG.

1.—Allanite and epidote in altered biotite-granite, Hildasay, Shetland Islands. 20581. × 12.

2.—Pale epidote surrounded by a fringe of later material; bunches of amphibole needles visible on the left. 20581. × 25.

3.—Xenotime surrounded by epidote. 20582. × 30.

4.—Corroded crystal of pale epidote. 20582. × 30.

(Slides in the collection of the Sedgwick Museum, Cambridge.)

PLATE XXIII.

Hand-specimen showing the development of kaemmererite in pale yellow secondary serpentine, on the surface of chromite-serpentine. Chromite quarries, Nikka Vord, Unst, Shetland Islands.

Actual dimensions of specimen 7 × 5 inches.

(Specimen now in the collection of the Department of Mineralogy, Cambridge.)

The Silica Lines of British Honduras.

By LESLIE H. OWER, F.G.S.

BRITISH Honduras may be briefly described as a 3,000 feet peneplain of upper Carboniferous slates, surrounded by thick dense Oligocene and Miocene limestones. The slates have a strike of about 250° conforming to the general Central American trend, produced at the close of the Palaeozoic. Granodiorite and quartz-porphyry were intruded at this period. The newer formations with their extension through Yucatan into Western Cuba, curve from north to north-east parallel to the rim of the 2,500 fathom Yucatan basin.

Foraminiferal Oligocene limestone, in the mountain area, rests directly on granodiorites and the upturned edges of the slates, and in the south-west reaches 2,500 feet altitude.

British Honduras has escaped the vulcanicity that in the neighbouring republics has continued since the close of Cretaceous times. The nearest eruptions are the basalts of Pleistocene age near Puerto Cortez in the Republic of Honduras.

The siliceous precipitations in the peninsula of Yucatan appear to be associated with the granodioritic magma that underlies Central America. Most of British Honduras has been permeated by siliceous waters during Upper Tertiary times and there is still sluggish hydro-thermal activity. When siliceous springs emerge on a land surface, sinter and quartzite may be expected, but the action of submarine siliceous springs is rather dubious. The British Honduras observations are that where the shallow sea floor contained contemporaneous calcareous accumulations, flint nodules have been formed, but elsewhere a fine sand has been deposited.

The formation of flint there appears to be a floor-level operation as the siliceous veins traversing limestone are quartzite. In that country most of the quartz veins are young, although some follow the edge of the granodiorite intrusions. It is one of these contact lodes that forms the highest point in the colony viz. the Cockscomb Peak, about 3,800 feet.

Silica solutions were extruded during Oligocene times, for a sandy limestone of that age has caused the development of the Pocton Pine Ridge. Further east the long E.–W. Quartz Ridge of 3,000 feet altitude, was probably formed at that period as still further east is one of the few localities where there are cherts in massive limestone. In the Cayo district, Miocene chalky marls, now elevated 600 feet, have abundant flint nodules. On the north side of the Mountain Pine Ridge, grit overlies the edge of the limestone and the plateau. A long line of quartz and quartzite reefs run south-westerly across the Mountain Pine Ridge forming prominent topographical features. The limestone to the south is very cavernous and the drainage underground, so the ascending warm waters probably did not reach the surface locally as siliceous material is absent there. In Guatemala at the foot of a N.W.–S.E. coastal fault traversing limestone, lies the township of Livingstone, built on a raised beach of large quartz pebbles, evidently derived from a young quartz vein in the vicinity. At Punta Gorda there is siliceous material on the beach, while quartz veins with grains of magnetite and a small gold content occur in the Pleistocene clay. This siliceous streak can be traced along the shore to the mouth of Deep River, where the coastal pine belt and narrow sandy beach commence and continue beyond Belize. These siliceous veins provide the sand favourable for the pines that dot much of the coastal plain and northern districts. The sea has only retreated from the coastal plain during Pleistocene times. Between Deep River and Bladen Branch there are a couple

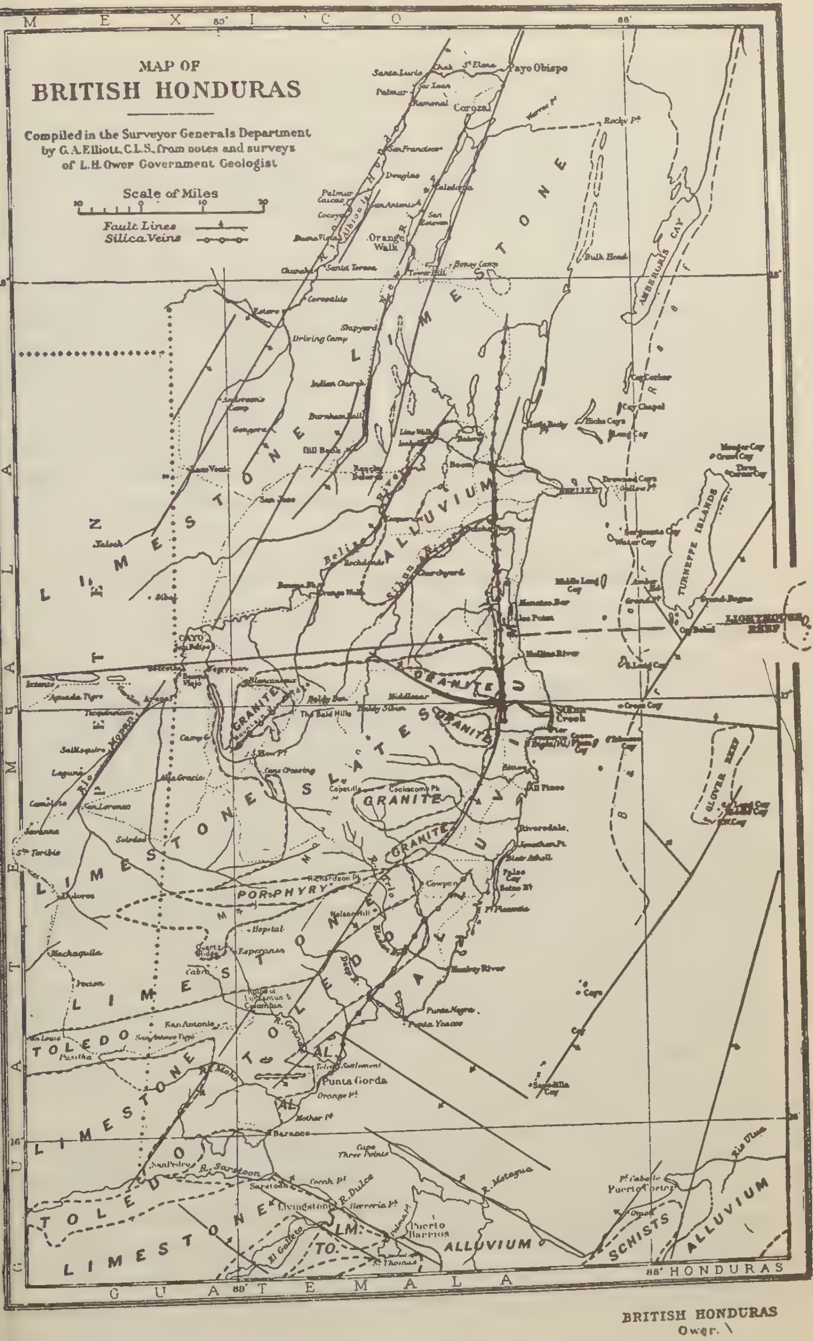

FIG. 1.—Map of British Honduras.

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of acres of low quartzite mounds about ten feet high but a conspicuous feature on this swampy country. Between Bladen and Swasey Branches are quartzite mounds more than double that magnitude. At Sennis Creek, to the north of Monkey River, there are deposits of grit surrounding a point of hydrothermal activity. Further north the coastal plain with its sandy clay foundation reveals little of interest except some quartzite on North Stann Creek. On Hector Creek, Sibun River, a long line of nodular flints, sometimes approaching 2 feet in diameter, commences. These are exposed on the surface in a low undenuded area and are best developed in the Northern River district and to the east of Orange Walk. The east side of the Rio Hondo is largely pine belt, the silica probably being derived from siliceous springs rising along fractures parallel with that stream. Usually flints are scarcer where the fine sand is plentiful. Salt water and calcareous mud appear essential for the growth of flints, a specially favourable locality being where siliceous springs discharge near the mingling of salt and fresh water.

Notes on the Geology of the Faeröe Islands.

By J. B. Simpson, B.Sc.Agri., B.Sc.

(PLATE XXIV.)

THE Faeröe Islands, 180 miles north-west of the Shetlands, are a part of that far-flung region known geologically as the Brito-Arctic or Thulean province of Tertiary volcanic rocks, here represented mainly by basalt lavas. Various investigators have visited them, and written about them from time to time, but as yet, no complete, detailed geological description of them has appeared. My acquaintance with them is limited to the islands of Stromöe and Suderöe, and my visit was of too short duration to allow much detailed field-work being done. These brief notes and analyses are presented now in the hope that they may be of use to other geologists.

The papers cited below are such as appear to furnish most information about the geology of these islands. Readers desirous of a more complete bibliography will find in them further references.

In 1821 the Faeröes were visited by Dr. Forchhammer[1] at the instance of the Danish government, and his report appeared in 1824. Just recently his diary[2] of the visit has been published.

Professor J. Geikie[3] has given us the most complete field-account of these islands. He travelled extensively throughout them in

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[1] Forchhammer, J. G., " Om Faeröernes geognostike Beskaffenhed," *Det kongl. danske Vidensk. Selsk. Skrifter*, 1824.

[2] " Rejse til Faeröerne, Dagbog," *Museum de Minéralogie et de Géologie de L'Université de Copenhague, Miscellanées* No. 7 and 8, 1927.

[3] Geikie, J., " On the Geology of the Faeröe Islands," *Trans. Roy. Soc. Edin.*, vol. xxx, p. 217.

1879, and his description, accompanied by a geological map, appeared in the *Transactions of the Royal Society of Edinburgh.* As this publication may not be readily accessible to many geologists at a distance from the larger scientific libraries I take this opportunity of reproducing Geikie's map so far as it concerns the general lava succession. In the original some dykes and glacial striae are also depicted.

A. Geikie [1] refers to them repeatedly.

Perhaps the zeolites that abound in the lava tops, have attracted most attention. They have been most zealously collected by Heddle, who refers to them throughout his writings, but he did not describe the collection as a whole. This service to geology, however, has been well performed by his friend and fellow-investigator, Dr. J. Currie.[2]

For petrographical descriptions of the basalts we have to turn to papers by Holmes [3] and Washington,[4] respectively. Their accounts are, in each case, accompanied by a chemical analysis.

In a paper recently published Peacock [5] discusses the development of the Fiord System.

A glance at the map shows that the geological structure of the islands is very simple in its broad outlines. They are built up almost entirely of flat or gently dipping flows of basalt lavas, separated by partings of bole or tufaceous grit. These lavas were poured out subaerially, but the floor on which they rest is nowhere visible. No centres of volcanic activity of any size are known within the present boundaries of the archipelago. The lava succession is interrupted by a thin sedimentary zone, seen in Suderöe and Myggenaes. The visible thickness of flows beneath this zone has been estimated at 4,000 feet by J. Geikie. They appear to be almost exclusively non-porphyritic in character. Above the sedimentary zone we have a vast pile of lava 9,000 or 10,000 feet thick. Uniformity in type, at least in Stromöe, is a character of this part of the succession also, but it differs sharply from the lower division in that phenocrysts of felspar are a feature in almost every flow.

Thus it is convenient to divide the lavas into a *Non-Porphyritic Lower Group*, and a *Porphyritic Upper Group*. According to Forchhammer the change in type of the lavas occurs at the sedimentary zone, and in this map the writer follows him, though he has not personally visited any locality where the sediments are exposed.

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[1] Geikie, A., *Ancient Volcanoes of Great Britain*, vols. i and ii.

[2] Currie, J., "The Mineralogy of the Faeröes, arranged Topographically," *Trans. Edin. Geol. Soc.*, vol. ix, pt. i, p. 1.

[3] Holmes, A., "The Basaltic Rocks of the Arctic Region," *Min. Mag.*, vol. 18, p. 180.

[4] Washington, H. S., "Deccan Traps and Other Plateau Basalts," p. 785, *Bull. Geol. Soc. Amer.*, vol. 33, pp. 765–804.

[5] Peacock, M. A., "Recent lines of Fracture in the Faeröes in Relation to the Theories of Fiord Formation in Northern Basaltic Plateaux," *Trans. Geol. Soc. Glasg.*, vol. xviii, pt. i, p. 1.

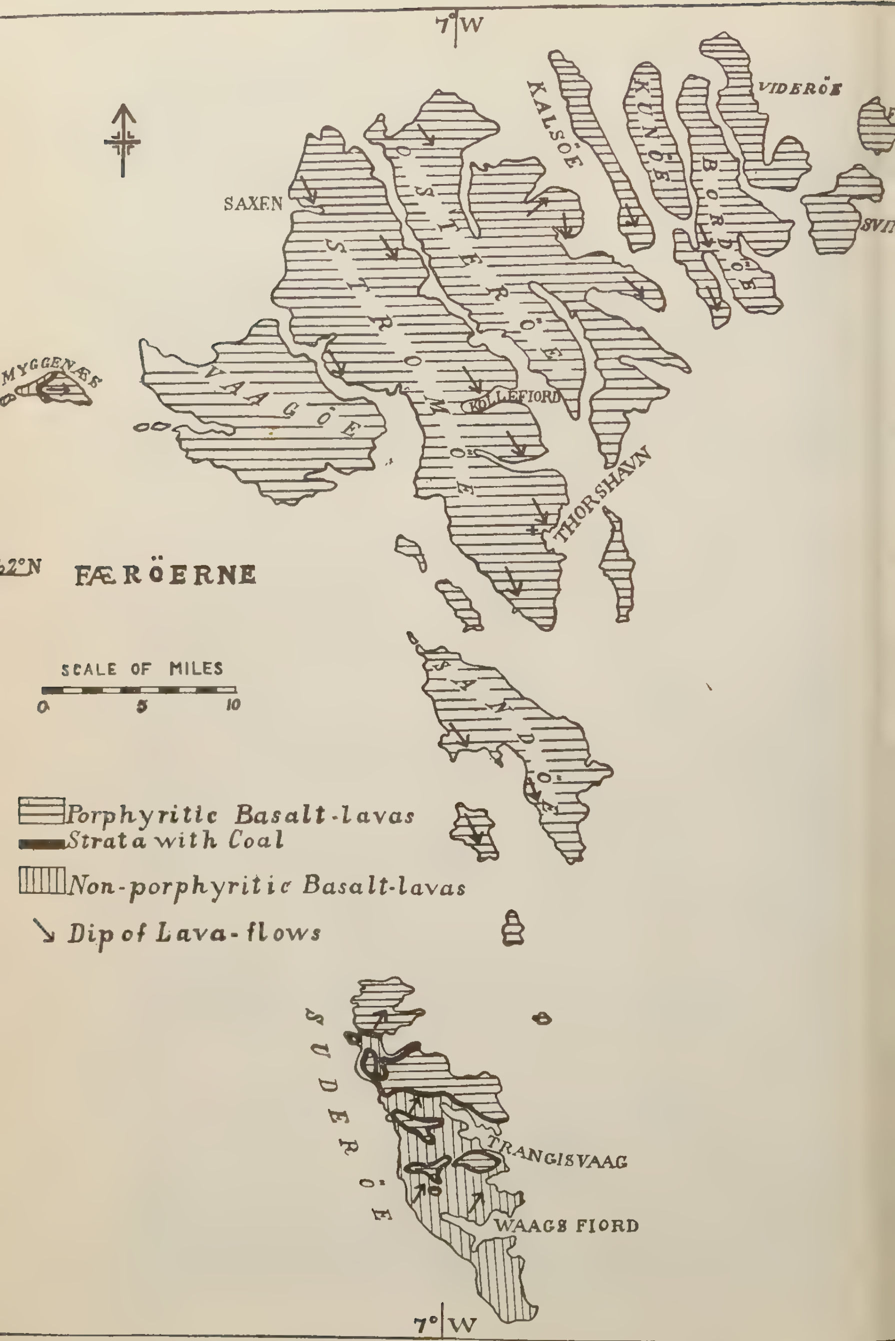

Fig. 1.—Map to illustrate the geology of the Faeröe Islands.

Non-Porphyritic Lower Group, Suderöe.—This group was examined at Trangisvaag and Waag. At these places time did not permit of an extended investigation, and details of the succession over an extended area cannot be furnished. All the flows seen were non-porphyritic.

The Trangisvaag rock has been analysed. In a slice (Pl. XXIV, Fig. 1), it is a fine- to medium-grained olivine-basalt. Serpentinized olivine is present as small (0·2 mm.) crystals in a matrix of granular augite and labradorite felspar. The augite shows a slight tendency to crystallize in two generations. The larger plates are sub-idiomorphic and display a very faint purplish tint, which is absent, or cannot be detected in the smaller anhedral granules. These are colourless or fawn. The felspar laths average less than 0·5 mm. in greatest length and there is an occasional larger crystal or glomero-porphyritic aggregate. Analcite in notable amount is apparent, as is also glass with a dark brown border and lighter yellow interior. Iron ore is present.

Holmes[1] gives a description, with an analysis by Harwood, of a specimen from Waagsfiord. This analysis is quoted for comparison. He found no olivine or analcite.

My specimen differs from that described by Holmes in the presence of notable amounts of olivine and analcite. This difference is reflected in the lower magnesia and higher silica of his analysis.

My own specimen from Waag is that of a fine-grained, non-porphyritic, olivine-poor basalt with abundant granular augite, similar to that described by Holmes.

Porphyritic Upper Group.—This group was studied in more detail in Stromöe. From Saxen on the north-west coast, to the extreme south point of the island the lavas everywhere dip south-east at a gentle angle (3°), and the uniformly porphyritic character of the flows is strikingly apparent. Very occasionally a non-porphyritic type is to be noted. In the majority of the flows the matrix is comparatively coarse-textured. In some it is extremely fine-grained and dense, with a glossy lustre. This latter type, like the non-porphyritic, occurs sporadically in single flows amongst the former. The coarse-textured variety weathers with a grey crust, the fine-textured and non-porphyritic with a black. A typical example of the coarse-matrixed variety, from the seashore at Hoivig, north of Thorshavn, has been analysed.

The felspar phenocrysts or glomero-porphyritic aggregates attain an average greatest length of from 5 to 7 mm. Exceptionally, single crytals 2 cm. or more in length may be noted. In this variety chlorophaeite in large lumps is common. In a thin slice (Pl. XXIV, Fig. 2) the felspar phenocrysts are seen to be basic labradorite or bytownite in composition. That of the ground mass is slightly less basic. The laths have an average length of 0·5 mm., and the granular aggregates of pale or fawn-coloured augite are correspondingly large.

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[1] Op. cit., p. 200.

There is no real ophitic structure. A little olivine is present, and a marked quantity of isotropic substance, dark-brown or olive-green in colour. This is probably chlorophaeite. Iron ore is not conspicuous.

The appearance of the fine-grained variety under the microscope is seen in Pl. XXIV, Fig. 3. The specimen is from the north side of Kolle Fiord, near the head of the fiord, and 800 feet above sea-level. The felspar phenocrysts are again labradorite or bytownite, set in a matrix of narrow elongated laths of labradorite, and granular augite. The augite is colourless or fawn. Magnetite with square outlines, sometimes included in the felspar, is plentifully distributed. Microphenocrysts of olivine may occur. These as a rule are entirely replaced by magnetite, and the paramorph is surrounded by an enhanced crystallization of granular augite—a reaction effect. We are unaware of alteration of this type having been previously described. Another good example of this type of lava is a thick flow quarried at the east breakwater of the harbour, Thorshavn. Washington[1] has described a specimen from Thorshavn, and his account is of a rock similar to mine except that no olivine was noted. I quote his analysis as typical of the fine-grained porphyritic variety. The non-porphyritic flows occasionally interspersed in the Porphyritic Upper Group are very fine-grained, and in slice, except for the absence of large phenocrysts, are in all other respects similar to the fine-grained porphyritic varieties.

We now possess four analyses of Faeröe basalts, and a comparison of them, *inter se*, is interesting. The Porphyritic Upper Group is characterized by a slightly higher percentage of SiO_2, and a markedly higher percentage of Al_2O_3, compared with the Non-Porphyritic Lower Group. The two new analyses show, too, a high percentage of TiO_2, a feature of high latitude Thulean basalts already pointed out by Holmes.[2] In the analysis of the basalt from Hoivig, the unusually large amount of H_2O at 105° C. is probably to be linked with the presence of chlorophaeite.

One analysis of a pre-glacial basalt from Iceland and three from Mull, Scotland, are reproduced for comparison.

Analysis (1) of the Trangisvaag basalt agrees fairly closely with analysis B of a Mull Plateau Type, and, compared with the majority of the Mull Plateau Type analyses, magnesia is rather low and lime rather high. The porphyritic tendency of the augite of the Trangisvaag rock is not found among Mull Plateau Types of basalt.[3] Analysis (2) of the Waag basalt (Holmes) corresponds quite well with analysis C of a Staffa Type from Mull, except that TiO_2 is higher and Al_2O_3 lower. My own slice from Waag would certainly be classed with the Staffa type if it occurred in Mull. Analyses (3) and

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[1] Op. cit., p. 785.

[2] Op. cit., p. 214 et seq.

[3] Cf. H. H. Thomas and E. B. Bailey, in "Tertiary and Post-Tertiary Geology of Mull, Loch Aline, and Oban," *Mem. Geol. Surv.*, 1924, p. 16.

(4) of basalts of the Porphyritic Upper Group, Stromöe, compare favourably with an example of the Porphyritic Central Type, Mull. The porphyritic lavas of the Faeröes would certainly be classed in Mull among the Porphyritic Central Types. The higher TiO_2 is noteworthy.

It may be recalled that, among the basalt lavas of Mull, the Geological Survey has distinguished a lower olivine-rich group without porphyritic felspars from an upper, olivine-poor group in which many flows carry felspar phenocrysts. The olivine-rich basalts of the lower group belong to what are called the Plateau Types. They are associated to a minor extent with olivine-poor types, including the Staffa Type. It has been shown that a somewhat similar association occurs in the lower group of the Faeröes, but it would be unwise to conclude yet that the prevalent olivine-richness of the Mull lower group is here reproduced. The material studied is too scanty for that, and further detailed field-work will be necessary to arrive at a true understanding of the position. As regards comparison between the upper groups of Mull and the Faeröes, it seems that porphyritic felspar is much more general in the latter.

Sills.—Only one conspicuous sill was noted on Stromöe. On Skaelling Fjeld at the head of Kolle Fiord, a columnar sill of dolerite cuts transgressively through the lavas. It is about 100 feet thick, and it is a conspicuous feature on the cliffs on the west side of the island. In a slice it is seen to be a beautifully fresh olivine-dolerite. The olivine, not a very abundant constituent, forms crystals, not exceeding ·3 mm. The augite, colourless or pale green, extinguishes at 40°, a diopsidic variety. It is in ophitic relationship with labradorite felspar. The rock is non-porphyritic. The felspars range in size between ·5 and 1 mm. Very little glass or isotropic material of any kind is present.

Dykes.—Several dykes were noted cutting the porphyritic lavas of Stromöe. These, with one exception, have directions varying between west 10° south, and west 10° north. The exception noted trended north and south. On the coast in every case examined, the dyke has proved less resistant to the waves than the bordering lavas, and long, narrow, straight-sided inlets called giovs have resulted. Inland, streams may run along them, and produce a similar feature. One of the most remarkable joins the through-valley between Kolle Fiord and Leinum. Here the lavas are cleft by a chasm 30 feet wide, with perpendicular walls rising to close upon 200 feet. A small stream flows down it, and a dyke runs along its length.

These east-west dykes all proved to be similar petrographically—olivine dolerites much richer in olivine than the olivine-poor basalts they cut. That shown in Pl. XXIV, Fig. 4, is typical. Olivine is abundant, analcite is scarce or absent. Perfect ophitic structure is exhibited by the felspar and augite. The north and south dyke, near the head of Kolle Fiord is quite distinct petrographically from those trending east and west. It is a fine-grained basalt, very similar to some of the non-porphyritic lava flows.

In conclusion I would express my grateful thanks to my colleague, Mr. E. B. Bailey, who has helped me much with this paper particularly as regards the comparison of Faeröe with Mull, and to Mr. T. C. Day, who has made the negatives of the photo-micrographs.

TABLE OF ANALYSES OF FAERÖE AND OTHER TERTIARY BASALTS.

	1.	A.	B.	2.	C.	3.	4.	D.	
SiO_2	45·40	45·37	48·79	49·70	49·76	46·40	47·58	47·24	S_1O_2
TiO_2	3·20	2·87	4·17	4·83	0·94	3·05	2·72	1·46	T_1O_2
Al_2O_3	14·54	15·16	11·96	10·98	14·42	16·30	17·12	18·55	Al_2O_3
Fe_2O_3	1·96	3·38	2·51	3·02	3·95	3·60	3·03	6·02	Fe_2O_3
FeO	10·45	11·58	12·10	11·19	7·77	7·17	8·73	4·06	FeO
MnO	0·25	0·31	0·21	0·22	0·20	0·23	0·14	0·31	MnO
MgO	6·25	6·72	5·60	5·34	5·30	6·00	5·18	5·24	MgO
CaO	11·72	8·11	10·15	9·71	10·22	11·04	10·12	11·72	CaO
Na_2O	2·08	2·90	2·40	2·22	2·49	2·14	3·89	2·42	Na_2O
K_2O	0·49	0·44	0·70	0·63	1·83	0·29	0·86	0·15	K_2O
H_2O+	1·50	1·96	0·40	0·96	1·03	1·10	0·13	2·24	H_2O+
H_2O-	2·00	1·18	0·65	0·92	2·04	2·40	0·06	0·21	H_2O-
P_2O_5	0·24	0·29	0·37	0·35	0·21	0·23	0'41	0·26	P_2O_5
CO_2	nt. fd.	—	0·41	—	0·06	nt. fd.	—	0·19	CO_2
S	trace	—	0·06	0·05	—	trace	—	nt. fd.	S
Total	100·08	100·27	100·59 [1]	100·18 [2]	100·30 [3]	99·95	99·97	100·12 [4]	

1. Lava, olivine-basalt. Trangisvaag, Suderöe, Faeröes. Non-Porphyritic Lower Group. Anal. W. H. Herdsman.

A. Lava, Mull. Basalt, Plateau Type. Quoted from Bailey and Thomas, *Tertiary and Post-Tertiary Geology of Mull, Loch Aline and Oban*, p. 15. Anal. E. G. Radley.

B. Preglacial, non-porphyritic basalt, Holmatindar, Eskifjord, Iceland. Quoted from Holmes, *Min. Mag.*, vol. 18, 1918, p. 192. Anal. Harwood.

2. Non-porphyritic basalt, Waagsfjord, Suderöe, Faeröes. Quoted from Holmes, *Min. Mag.*, vol. 18, p. 201. Anal. Harwood.

C. Lava, Mull. Basalt, Staffa Type. Quoted from Bailey and Thomas, *Tertiary and Post-Tertiary Geology of Mull, Loch Aline and Oban*, p. 17. Anal. E. G. Radley.

3. Lava, basalt. Hoivig, Stromöe, Faeröes. Porphyritic Upper Group. Anal. W. H. Herdsman.

4. Basalt, porphyritic, Thorshavn, Stromöe, Faeröes. Quoted from H. S. Washington, *Deccan Traps and Other Plateau Basalts*, p. 786. Anal. H. S. Washington.

D. Lava, Mull. Basalt, Porphyritic Central Type. Quoted from Bailey and Thomas, *Tertiary and Port-Tertiary Geology of Mull, Loch Aline and Oban*, p. 24. Anal. E. G. Radley.

[1] Includes Cr_2O_3, trace; V_2O_3, 0·11; NiO, trace; BaO, trace.

[2] Includes Cr_2O_3, trace; V_2O_3, 0·03; BaO, 0·01; Cl, 0·02.

[3] Includes LiO_2, trace; BaO, 0·04, FeS_2, 0·04.

[4] Includes (Co, Ni)O, 0·05.

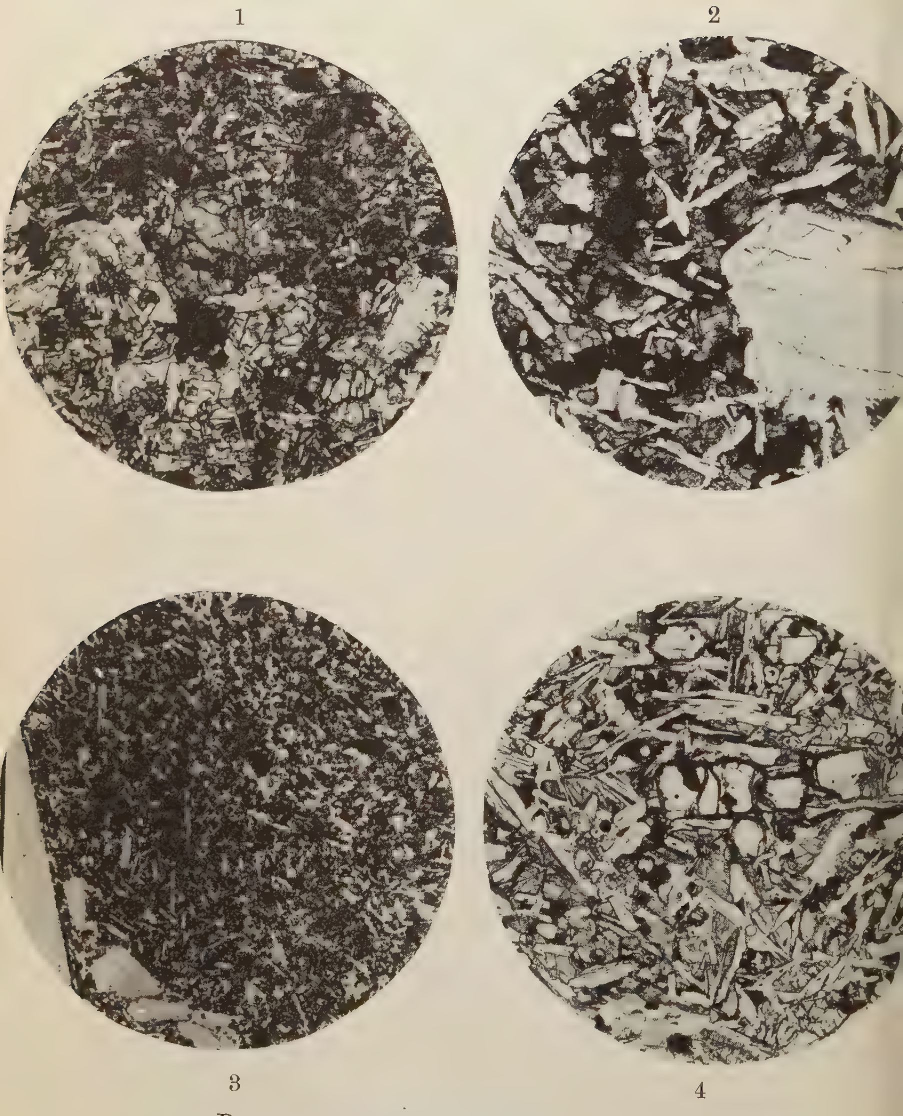

PHOTO-MICROGRAPHS OF FAERÖE ROCK TYPES.

o face p. 517.]

EXPLANATION OF PLATE XXIV.

Fig.

1.—*Olivine-basalt lava*, Non-Porphyritic Lower Group, Trangisvaag, Suderöe. Sub-idiomorphic plate of augite in centre, in a base of granular augite, labradorite felspar, olivine, and analcite. Ordinary light, × 25.

2.—*Basalt lava*, Porphyritic Upper Group, Hoivig, Stromöe. Phenocryst of basic labradorite in a very coarse matrix of granular augite and felspar, and black patches of chlorophaeite. Ordinary light, × 25.

3.—*Basalt lava*, Porphyritic Upper Group, Kolle Fiord, Stromöe Phenocryst of basic labradorite in a fine-grained matrix of granular augite and felspar. The black clots are paramorphs of olivine occupied by magnetite grains, and surrounded by a dense crystallization of augite. Ordinary light, × 25.

4.—*Olivine-dolerite*, east-west dyke, Leinum, Stromöe. Ophitic intergrowth of augite and felspar, olivine. Ordinary light, × 25.

On the Occurrence of Linnaeite in the Coal-measures of South Wales.

By W. E. Howarth (Department of Geology, National Museum of Wales).

IN the course of an investigation into the distribution of millerite by Dr. F. J. North and the writer,[1] the presence of linnaeite (sulphide of cobalt Co_3S_4) in the clay-ironstone nodules of the Coal-measures of East Glamorgan was confirmed. That sulphide of cobalt should accompany sulphide of nickel is not surprising, but the only record of its occurrence in Wales so far as the writer is aware, takes the form of a note (without title) by A. L. des Cloizeaux in a French publication.[2] This record was based on a specimen from the "Rhonda" (Rhondda) discovered by a Mr. Terrill, of Swansea, which does not seem to have been preserved. It is possible, too, that the mineral may occur in the Coal-measures of Belgium, as nickel and cobalt were detected in the soot from flues under which coal from Beyne (near Liége, Belgium) had been burned.[3]

The linnaeite in South Wales occurs as minute octahedra or aggregates of octahedra (sometimes twinned) averaging about 0·4 mm. in diameter : the crystals are usually found loosely attached to the dolomite or ankerite which lines the septarian cracks in the clay-ironstone of East Glamorgan, though in one locality the mineral occurred in black granular iron pyrites.

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[1] "On the Occurrence of Millerite and Associated Minerals in the Coal Measures of South Wales," *Proc. South Wales Inst. Engineers*, vol. xliv, No. 3 (1928), pp. 325–48.

[2] *Bulletin de la Société Minéralogique de France*, tome iii^e (1880), pp. 170–1.

[3] A. Jorissen, "Sur la présence du molybdine, etc., dans le terrain houiller du pays de Liége," *Ann. Soc. Geol. Belg.*, vol. xxiii, 1896, pp. 101–5.

Of the seventeen localities in which millerite has been detected six also yielded linnaeite, viz. :—

Locality.	Horizon.	Occurrence.	Minerals accompanying Linnaeite.
Treharris	Clay-ironstone accompanying Seven Feet Seam.	On dolomite lining septarian cracks.	millerite, kaolinite, chalcopyrite, barytes.
Bedwellty	Clay-ironstone accompanying Elled Vein.	,,	millerite, quartz (" diamond "), kaolinite, blende, chalcopyrite, a hydrocarbon (hatchettine).
Cymmer (Porth)	Clay-ironstone accompanying Two Feet Nine Seam and Five Feet Seam.	,,	millerite, calcite, kaolinite, blende, chalcopyrite, a hydrocarbon (hatchettine ?).
Newbridge	Clay-ironstone accompanying the Black Vein.	,,	millerite, quartz, galena, chalcopyrite, a hydrocarbon (hatchettine ?).
Ferndale No. 1 Pit	In granular iron pyrites *in* Two Feet Nine Seam.	On dolomite lining a vertical crack.	millerite, chalcopyrite, kaolinite.
Bargoed, Powell Dyffryn Pit	In clay ironstone, accompanying the Four Feet Seam.	On dolomite lining septarian cracks.	millerite, chalcopyrite, kaolinite, galena.

In all the occurrences tabulated above, the linnaeite had been deposited either directly on the dolomite coating the cracks or on the millerite, showing that its formation was subsequent to these, but as it was never found in contact with galena, blende, or chalcopyrite, its relation to those minerals could not be determined.

The origin of the cobalt and of the nickel is discussed in the paper already cited, and further work on the distribution and significance of the presence of hydrocarbons is being carried out.

The Lower Carboniferous of the Skyreholme Anticline, Yorkshire.

By F. W. Anderson, B.Sc., University of Leeds.

THE Skyreholme anticline is that part of the Craven Lowlands south of the North Craven Fault, which lies between Greenhow and Burnsall, east of Grassington. Exposures are mainly found in Troller's Gill, the valley of Skyreholme Beck, in Reynard's Gill, a deserted stream bed, and on the limestone pavements of Green Grooves.

These limestones have hitherto been considered to be of Reef

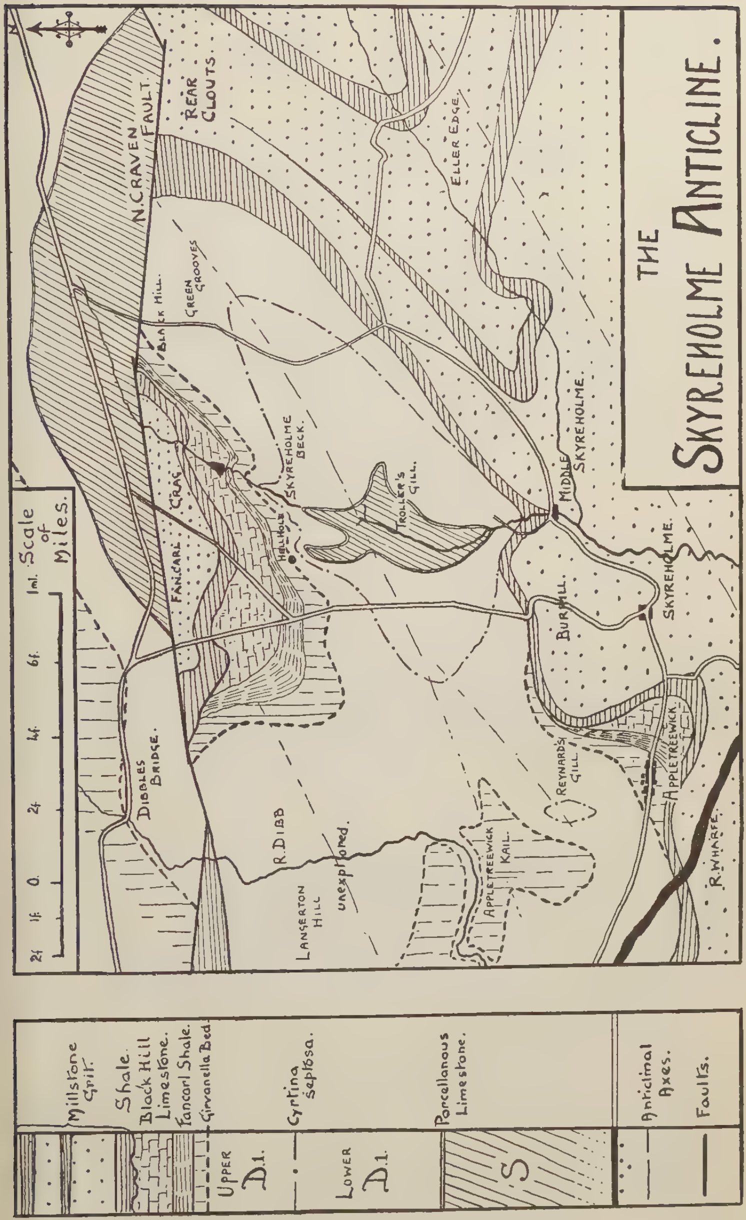

FIG. 1.—Map of the Skyreholme Anticline.

facies (Wilmore, *Q.J.G.S.*, vol. lxvi, 1910, p. 539, Garwood and Goodyear, *Q.J.G.S.*, vol. lxxx, 1924, p. 184), but a detailed examination of the area shows them to be, both in lithology and fauna, more related to the Northern facies type of deposit than either to the Culm or to the Reef facies of the Craven Lowlands.

Structurally, the region is anticlinal, a series of anticlines *en echelon*, with the N.E.–S.W. trend predominant in the district,[1] the whole being very much broken up by faulting, which, however, is nowhere sufficiently strong to obscure the general structure. The majority of the faults are connected with the North Craven Fault, which here at its eastern end becomes a compound fracture, the many bivirgations having a general N.W.–S.E. trend considerably diminishing the throw. Although mapped on a 6 in. scale these minor faults have not been thought of sufficient importance to be reproduced on the map accompanying this paper.

The general sequence of the beds exposed is as follows :—

Millstone Grit :	Grassington Grit.
Carboniferous Limestone :	D_2 Limestones and shales. D_1 Limestones, crinoidal and cherty in the upper beds. S Porcellaneous limestones and calcite mudstones.

Lithological and Faunal Sequence.

S Beds.—Beds of *S* age are exposed on the axis of the Skyreholme anticline in Troller's Gill, and that of the subsidiary anticline of Reynard's Gill. They are creamy-white, very compact limestones almost devoid of fossils, with the exception of a Productid band under the Porcellanous bed. The upper limit of *S* is taken to be the top of the Porcellanous bed and the base is not seen.

Sequence :—

(*c*) Porcellanous beds with first minor Productid phase at the base.
(*b*) Light-grey, slightly crinoidal limestones.
(*a*) White limestone and calcite mudstone.

The fauna of the Productid band is as follows :—

Productus sp. *maximus* group (two vars., abundant).
Pustula spinulosa.
Reticularia lineata.
Schizophoria resupinata.
Syringopora sp.

The presence of strong permanent springs where the lowest beds are exposed in Troller's Gill suggests that here the *S* beds rest on a pre-Carboniferous ridge.

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[1] For a fuller discussion of the general geology of the surrounding districts see : R. G. S. Hudson, *General Handbook, Brit. Assoc., Leeds Meeting,* 1927, pp. 25–31.

D_1.—The D_1 beds are well exposed. North of Appletreewick Kail and on Green Grooves they show the well-known "karst" conditions, developing the griky pavements seen in the Ingleborough district.

Sequence :—

Upper D_1	(*j*) *Girvanella* bed.
	(*i*) Crinoidal beds with major Productid phase.
	(*h*) Cherty beds.
	(*g*) Grey limestones.
	(*f*) Limestone brash with *Cyrtina septosa.*
Lower D_1	(*e*) Grey limestones, slightly crinoidal.
	(*d*) White, Reef-like limestone.

Lower D_1.—(*d*) The extremely compact white limestones at the base of D_1 are exposed in Reynard's and Troller's Gill, those of the former locality containing a gastropod-lamellibranch fauna more akin to that of the Reef limestones than to a Northern facies fauna. Typical Reef brachiopods found in this bed are :—

Brachythyris glabra.
Brachythyris decora.
Pugnax acuminatus.

(*e*) These massive and unfossiliferous limestones form the bold scarps of Jackdaw Nick and Old Man's Scar in Troller's Gill, and the walls of a seventy-foot-deep pothole in Reynard's Gill.

Upper D_1.—The top of upper D_1 is taken to be a black limestone with *Girvanella*, the base a limestone containing *Cyrtina septosa.*

(*f*) The *Cyrtina* bed is a fine fragmental limestone exposed in the Gills and on the griky pavements of Green Grooves, east of Skyreholme Beck, and containing, besides *Cyrtina septosa*, *Chonetes papilionacea*, *Cyathophyllum murchisoni* cf. var. *pendelense*, *Diphyphyllum* sp.

Although the divisions thus constituted by taking the *Cyrtina septosa* bed as the base of upper D_1 are very unequal, faunally, there is good reason for this division of the beds. The *Cyrtina septosa* bed inaugurates conditions under which the limestones become very rich in fossils as contrasted with the barrenness of the underlying beds.

(*g*) Massive grey limestones 35–40 ft. thick, with very few fossils.

(*h*) A series of dark limestones with chert is typically exposed in Reynard's Gill. It may be divided into three divisions, chert occurring only in the upper and lower parts as follows :—

(3) Dark massive limestones with nodular chert, 15 ft.
(2) White limestone without chert, 20 ft.
(1) Rubbly grey limestone with layered chert, 5 ft.

The white limestone contains an oolite pebble bed, the pebbles being well rounded and also of white limestone.

(*i*) Above are beds which in the upper parts become very crinoidal. In general they are without chert but as exposed in Hell Hole and

Gill Head's Gully chert is found some 15 ft. from the base. These limestones contain an important faunal phase (the major Productid phase), a band extremely rich in Productids of a *giganteus-maximus* type. The shells are large, thick and strongly curved, with long spines on the hinge line and ears, evidently a katagenetic form. The horizon is on this account easily traceable throughout the area, though the diagnostic species are as yet undescribed.

The forms present are :—

Productus sp. *giganteus* group.
Productus sp. *giganteus-maximus* group (three varieties).
Productus sp. *maximus* group (four varieties).
Productus sp. *semireticulatus* group (two varieties).
Productus sp. *productus* group (three varieties).
Productus cf. *insculptus.*
Spirifer bisulcatus.
Brachythyris sp.
Spirifer crassus.

(*j*) The *Girvanella* bed is a dark shaly limestone with *Girvanella*, underlain by 2 inches of shale and 1 foot of limestone containing algal nodules. The bed is typically exposed in Hell Hole.

Towards the top of D_1 and associated with the *Girvanella* bed is a rich coral fauna, D_1 Lithostrotion and Caninoid forms being particularly abundant.

Coral Fauna of Upper D_1 :—

Clisiophyllum sp. (D_1 form).
Dibunophyllum sp. (D_1 form).
Lithostrotion cf. *basaltiforme* (common).
Lithostrotion cf. *martini.*
Lithostrotion cf. *portlocki.*
Lonsdaleia floriformis floriformis (early form).
Aulophyllum fungites mut. *redesdalense* towards *pachyendothecum.*
Caninia benburbensis (abundant).
Caninia sp. (cf. *Caninia samsonensis*).

D_2.—These beds occur in three small patches :—

(1) Exposed in the northern part of Skyreholme Beck, underlying the Grit and brought up against D_1 and S beds to the north by the Craven Fault.

(2) In an old level between Appletreewick and Skyreholme.

(3) Forming the cap of Appletreewick Kail, west of Reynard's Gill.

The succession is as follows :—

(*m*) Limestone 50 ft. (Black Hill Limestone).
(*l*) Shales with limestone 50–60 ft. (Fancarl Series).
(*k*) Limestone 20 ft.

(*k*) Above the *Girvanella* bed are 20 ft. of dark limestone containing *Saccamina carteri* and stick bryozoa.

(*l*) The Fancarl Series are shales with thin black limestones containing two Zaphrentid phasal faunas separated by a black limestone with *Aulophyllum.*

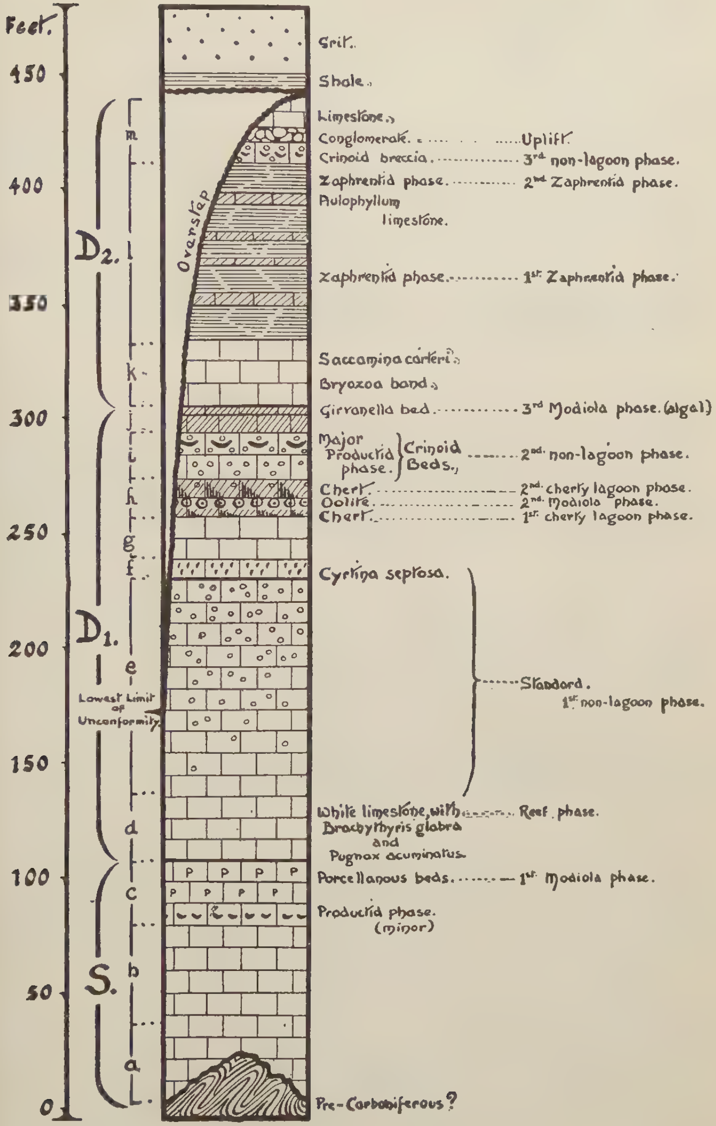
Feet.
450
400
350
300
250
200
150
100
50
0
D2.
D1.
S.
m
l
k
j
i
h
g
f
e
d
c
b
a
Lowest Limit of Unconformity.
Overstep
Grit.
Shale.
Limestone.
Conglomerate. ...... Uplift.
Crinoid breccia. ...... 3rd non-lagoon phase.
Zaphrentid phase. ...... 2nd Zaphrentid phase.
Aulophyllum limestone.
Zaphrentid phase. ...... 1st Zaphrentid phase.
Saccamina carteri.
Bryozoa band.
Girvanella bed. ...... 3rd Modiola phase. (algal)
Major Productid phase. } Crinoid Beds. ...... 2nd non-lagoon phase.
Chert. ...... 2nd cherty lagoon phase.
Oolite. ...... 2nd Modiola phase.
Chert. ...... 1st cherty lagoon phase.
Cyrtina septosa.
Standard. 1st non-lagoon phase.
White limestone, with Brachythyris glabra and Pugnax acuminatus. ...... Reef phase.
Porcellanous beds. ...... 1st Modiola phase.
Productid phase. (minor)
Pre-Carboniferous?

FIG. 2.—The Succession of Strata in the Skyreholme Anticline.

The lower Zaphrentid shales yield :—

Spirifer bisulcatus (very abundant).
Densiphyllum cf. *charlestonensis.*
Zaphrentis densa.
Zaphrentis disjuncta (early).
Zaphrentis omaliusi.
Zaphrentis cf. *parallella.*

with small limestone bullions and pyritous concretions.

The upper shale contains crinoid and ophiuroid fragments and numerous fish remains—scales, spines, and coprolites. Also :—

Chonetes sp.
Pustula aculeata.
Terebratula vesiculosus.
Limatulina alternata.
Pseudamusium anisotum.
Zaphrentis delanouei (cf. *parallela*).
Zaphrentis cf. *densa.*
Zaphrentis sp.

The black limestone contains :—

Aulophyllum fungites mut. *redesdalense* towards *pachyendothecum* (abundant).

(*m*) The Black Hill Limestone was formed under two distinct conditions of deposition separated by an interdepositional conglomerate. The lower beds are a very heavily crinoidal limestone, cherty in the upper parts and rich in Productids. (Second minor Productid phase.)

Fauna of the Crinoidal Limestone :—

Productus sp. *maximus* group.
Productus sp. *productus* group.
Productus sp. *semireticulatus* group.
Productus antiquatus.
Productus cf. *insculptus.*
Productus sp. towards *margaritaceus.*
Productus aff. *pugilis.*
Pustula aff. *eximea.*
Pustula spinulosa.
Chonetes buchiana.
Spirifer integricostus.
Spirifer biplicatus.

The upper beds are compact, unfossiliferous grey limestones, at the base of which is a conglomerate, both pebbles and matrix being of a fine-grained grey limestone very similar in character to the beds above, but apparently bearing no lithological relation to the crinoid breccia below.

The Millstone Grit.—On the flanks of the Skyreholme anticline the limestones are overlaid by a massive grit—the Grassington Grit, with a thin shale at the base.

That the Millstone Grit is here resting unconformably on the limestone is made evident by a marked overstep, and at the northern end of Skyreholme Beck, by a difference of dip. It has been shown by Hudson and Chubb (*Proc. Yorks. Geol. Soc.*, vol. xx, 1925, pp. 257–91) for the area north of the Craven Fault, that there is an overstep of the Millstone Grit from south to north. In Coverdale the Millstone Grit rests on the Undersett Limestone, at Coniston on O beds, at Appletreewick Moor on D_2, at Keld Houses on D_1, at Coldstones and Toftgate on D_2 and O respectively, thus placing the axis of uplift somewhere near Greenhow Hill, running N.E.–S.W.

From the foregoing evidence it is apparent that the unconformity is continued to the south of the Craven Fault. In the northern part of the area the Grit of Fancarl Crag rests on D_2 beds, at Rear Clouts on upper D_1, at Middle Skyreholme on middle and lower D_1, at Birkhaw Hill on upper D_1, at Appletreewick on D_2, and at Hartlington again on D_1. Moreover, since the axis of uplift is traceable south of the Fault and follows the line of the Skyreholme anticline, it is probable that this anticline is a posthumous fold on that line of uplift. That the beds are not overstepped with the same regularity as on the rigid block points to a folding and considerable denudation in pre-Millstone Grit and post-Lower Carboniferous times.

CORRELATION.

The presence of well-marked faunal bands in the limestones of the Skyreholme anticline allows of correlation with the Northern facies limestones of adjacent areas north of the Craven Fault.

The Porcellanous beds are correlated with the Porcellanous beds of Garwood and Goodyear (*Q.J.G.S.*, vol. lxxx, 1924, p. 184) and of Chubb and Hudson (*Proc. Yorks. Geol. Soc.*, vol. xx, 1925, pp. 257–91) on lithological similarity alone.

The *Cyrtina septosa* band is a widespread and reliable horizon in the upper D_1 limestones north of the Craven Fault.

The black limestone with *Girvanella*, here, as in the Northern Province generally, is taken to mark the top of D_1. In the upper beds of D_1 and closely associated with the *Girvanella* bed is a rich coral-brachiopod fauna which may be compared with that occurring at the same horizon at Dibbles Bridge, a section exposed just north of the Craven Fault in the bed of the River Dib. As the predominant corals are Lithostrotion and Caninoid forms, and the brachiopods mainly of the *Productus* sp. *maximus* group, this phase may be equivalent to the " limestones with *P. maximus* " of Settle (Garwood and Goodyear, *supra cit.*) and to the " limestones with *P. maximus* and reefs of *Lithostrotion* " of Wensleydale (Hudson, GEOL. MAG., Vol. LXII, 1925, p. 182) all occurring in the same stratigraphical position, i.e. just below the *Girvanella* bed.

The D_2 beds are, in part, the Lower *Lonsdaleia* beds of Garwood. Immediately above the *Girvanella* bed is a limestone representing the upper part of the Great Scar Limestone, and here as in Wensleydale contains a *Saccamina carteri* band.

The Fancarl Series with a Zaphrentid phasal fauna may be taken to be equivalent to the Gayle Shale of the Yoredale series (Hudson, GEOL. MAG., Vol. LXII, 1925, p. 184).

The Black Hill Limestone with Productids as the dominant form in the lower fossiliferous beds, is comparable with the Gayle

Limestone in which also Productids are abundant. The uppermost black limestone of the Fancarl Series (shales with thin posts of black limestone), with its *Aulophyllum* fauna, may be compared with Garwood's " shale with *Aulophyllum* " found at Fairweather Springs, Ingleborough, 52 ft. above the *Girvanella* bed (Garwood and Goodyear, *supra cit.*).

When correlating the beds of this area with Northern facies limestones of other areas it must be noted, however, that in the Appletreewick district the conditions of deposition were by no means normal. Less than 3 miles to the west the Reef limestones are fully developed, and passing westwards from Troller's Gill the beds change rapidly from limestones of the Northern facies type to those of Reef facies type, becoming conspicuously lighter in colour and bearing a different and more abundant fauna.

DISCUSSION.

Although previously considered as belonging to the Reef Limestone type of deposit, the limestones of the Skyreholme anticline are now shown to belong to the Northern Province basin of sedimentation. They are, in the main, limestones of the lagoon-phase type, using " lagoon-phase " in the sense indicated by Dixon (*Q.J.G.S.*, vol. lxvii, 1911, p. 511). The S and D_1 beds, with the exception of two periods of non-lagoon conditions and one of Reef deposits, are predominantly of the *Modiola*—calcareous lagoon—phase. The calcite mudstones of upper S (*Modiola* phase) are succeeded by compact white limestones, which, faunally and lithologically, are of Reef type. These in turn are succeeded by a series of standard limestones deposited during the first period of non-lagoon conditions, a phase ending with the deposition of a mass of fine crinoidal *débris* —the *Cyrtina septosa* bed. Then in upper D_1 came two periods during which beds of the cherty lagoon type were deposited—the two main developments of bedded cherts, separated by an oolite (calcareous lagoon phase) a deposit requiring the slow deposition of calcium carbonate at a depth approaching the limit of wave action, i.e. 35 fms. The cherty beds are overlain by massive crinoidal limestones, crinoid breccias in the upper parts, evidently swept in from some outside source by swift currents. This constitutes the second non-lagoon phase, which was followed by a considerable development of the coral fauna, culminating in the algal limestones of the *Girvanella* bed horizon. As in the Settle area the *Girvanella* nodules are not confined to one bed, but, though more abundant at a certain horizon, occur sporadically in the beds below and above. The presence of stick bryozoa below the *Saccamina carteri* bed is consequent on the same phase of deposition.

The D_2 beds of the area, in the main, are of the Zaphrentid-Cyathaxonia phase, bearing the " modified limestone fauna " of Hudson (*Proc. Yorks. Geol. Soc.*, vol. xx, 1923–4). They are typically black calcareous shales, often slaty in character and containing thin beds of evenly bedded, dark argillaceous limestone, the fossils being simple corals, mainly zaphrentids, bryozoa, crinoids, small athyrids, pustulids (generally *P. pustulosa*). *Schizophoria resupinanta* and fish remains.

The Black Hill Limestone is, in the lower parts, a heavy crinoidal breccia, composed almost entirely of large crinoid stem fragments with bands of worn and crushed Productids, evidently a recurrence of non-lagoon conditions. The highest beds of the crinoidal breccia are cherty, indicating that they were followed by a cherty lagoon phase, initiating an uplift which resulted in the interformational conglomerate at the base of the upper Black Hill Limestone.

Considering the above evidence, it follows that the relation of the boundary of the Northern Basin of deposition to the North Craven Fault is capable of two interpretations :—

(1) If the North Craven Fault was, as suggested by Tiddeman (*Rep. Brit. Assoc., Newcastle*, 1889) initiated in Lower Carboniferous times and formed a boundary to the Northern basin, then there was (a possibility also considered by Tiddeman) a transgression round the eastern end of the fault where the throw had become considerably less.

(2) On the other hand, an entirely post-Carboniferous age for the Craven Fault may be postulated : a solution which is suggested by the foregoing evidence.

SUMMARY.

The area east of the Burnsall Knolls in the north-east Lowlands of Craven is occupied by limestones of the Northern facies type, apparently unaffected by the presence of the North Craven Fault. The beds are overlain unconformably by the Grassington Grit, which, overstepping the flanks of the Skyreholme anticline, thus continues to the south the unconformity noticed north of the fault. It is suggested hat the line of the Skyreholme anticline is the axis of uplift which gave rise to pre-Millstone Grit denudation. Passing westwards the beds become Reef-like in character and eventually grade into the Reef limestones of Burnsall.

Finally, my best thanks are due to Mr. R. G. S. Hudson for much help and guidance during the progress of the above work.

REPORTS AND PROCEEDINGS.

Liverpool Geological Society.

9th October, 1928.

The President, Dr. E. Neaverson, read an Address, entitled: "Faunal Horizons in the Carboniferous Limestone of the Vale of Clwyd.".

The Vale of Clwyd lies essentially in Silurian rocks, being bordered by the Denbighshire Moors on the west and the Clwydian Hills on the east. A fringe of Carboniferous rocks separates these ancient rocks from the Triassic and Drift deposits which occupy the centre of the Vale. The address gives an interpretation of the Carboniferous faunal succession suggested by recent investigations.

The Carboniferous deposits of the interior of the Vale differ lithologically and faunistically from those at the north-eastern border. The lower D_1 limestones along the western side, from Ruthin to Abergele, are fine-grained porcellanous rocks containing an abundance of *Daviesiella llangollensis* (Dav.) almost to the exclusion of other fossils. They are overlain by the "White Limestones" of Morton and the Geological Survey, which are here referred to D_1 on evidence of the coral fauna. The succeeding D_2 limestones, south of Llanfair D.C., contain *Lonsdaleia floriformis* and other fossils. The lowest D_3 horizon is a dark *Saccamina* limestone occurring at Craig fechan (east of Llanfair D.C.), where it is overlain by sandy limestones and coral-beds, with a typical "Yoredale" fauna. The coral-beds are also exposed at the well-known prolific collecting-grounds of Faenol and Tyn Llanfair.

Between Dyserth and Prestatyn the succession is :—

D_3. Reef-knolls with many brachiopods and *Goniatites crenistria* at Meliden, etc.; dark limestones with *Cyathaxonia* near Prestatyn.

D_2. Grey limestones with *Chonetes siblyi* Thomas, and other brachiopods; *Caninia* beds with *C. juddi* Thoms., *Zaphrentis konincki* E. & H., etc.

D_1. Brown and grey limestones with *Palaeosmilia murchisoni.* Impure brown limestones with *Composita* cf. *ficoidea,* corals and plants.

Among the striking faunal differences described are: The virtual absence of *Daviesiella llangollensis* from D_1 of the Dyserth area; the apparent absence of *Lonsdaleia floriformis* from the Prestatyn district, where the peculiar *Caninia* fauna and the later brachiopod assemblage are conspicuous; the contrast between the D_3 Yoredale fauna of the southern area and the equivalent reef-knoll facies of the north-eastern border. The latter are correlated by the occurrence in each of certain corals.